DECISION ANALYSIS METHODOLOGY TO EVALUATE

INTEGRATED SOLID WASTE MANAGMENT ALTERNATIVES

FOR A REMOTE ALASKAN AIR STATION

THESIS

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Captain Mark J. Shoviak

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List of Acronyms

AAC – Alaska Administrative Code

ADEC – Alaska Department of Environmental Conservation

AFB – Air Force Base

AFI – Air Force Instruction

AS – Air Station

ASG – Air Support Group

BOS – Base Operations Support

CES – Civil Engineer Squadron

CFR – Code of Federal Regulations

DM – Decision-Maker

EAS – Eareckson Air Station

EO – Executive Order

EPA – Environmental Protection Agency

ISWM – Integrated Solid Waste Management

MRF – Materials Recovery Facility

MODA – Multiple-Objective Decision Analysis

MSW – Municipal Solid Waste

MSWLF – Municipal Solid Waste Landfill

O&M – Operations & Maintenance

PPA – Pollution Prevention Act

USAF – United States Air Force

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Abstract

Eareckson Air Station (AS), a remote U.S. Air Force installation, faces the complex decision of selecting a new municipal solid waste (MSW) management strategy to replace its current non-compliant system. This research effort applies value-focused thinking and multiattribute preference theory to decision analysis techniques to produce a multiple-objective decision analysis model that captures all of the site's MSW goals, objectives, and concerns in order to facilitate the evaluation of MSW management strategies available. The model ranks 40 specific MSW management alternatives, which were developed in accordance with the decision-maker's assumptions and constraints, based on how well they meet Eareckson's overall strategic objective, a 20-year compliant MSW system. The model provides insight to the decision-maker as to which strategy is best suited for Eareckson's MSW management needs. Sensitivity analysis is incorporated in the model to assess and illustrate the effects of changes in model objective weights and changes in model parameters. Overall, the model provides the Eareckson AS decision-maker with a decision tool to make a better decision when choosing a new MSW management strategy.

The model results suggest that the Eareckson AS MSW strategy should be a Class II municipal solid waste landfill (MSWLF) along with a recycling combination that includes at least paper and cardboard recycling. The top-ranked alternative consists of a Class II MSWLF along with recycling aluminum cans, steel cans, glass, paper, and cardboard. Sensitivity analysis shows that this top-ranked alternative is relatively insensitive.

DECISION ANALYSIS METHODOLOGY TO EVALUATE

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Chapter 1. Introduction

1.1 Background

The management of municipal solid waste (MSW) is a high priority issue for many communities throughout the nation. Rising MSW generation rates and disposal costs, environmental and health concerns, limited landfill space, legislative changes, political climate, and social attitudes have a significant impact on waste management efforts. Increasingly, many communities are adopting the concept of integrated solid waste management (ISWM) as a means of better managing their MSW rather than burying all of their waste in landfills. Integrated solid waste management (ISWM) is a practice using several alternative waste management techniques to manage and dispose of specific components of the municipal solid waste stream (USEPA, 1999a: 13). Typical waste management alternatives include source reduction, reuse, recycling, composting, landfilling, and waste combustion.

In 1989, the U.S. generated 269 million tons of MSW. An estimated 84 percent of this waste stream was disposed of in landfills, 8 percent was incinerated, and 8 percent was recycled. While MSW generation in the U.S. increased to an unprecedented high of just under 375 million tons in 1998, the proportion of the total MSW landfilled decreased to an all-time low of 61 percent. In addition, the proportion of the total MSW recycled

increased to a record high of 31.5 percent, while incineration disposal slightly decreased to 7.5 percent (Glenn, 1999: 68). Part of the reason for the decrease in land disposal is that the federal government and most state legislatures have passed laws over the past decade requiring diversion of MSW from landfills. In addition, environmental contamination has prompted stringent regulation of landfills which has increased landfill siting, construction, and operations costs. As a result, the difference between the cost of landfilling and other waste management options has narrowed significantly in many parts of the U.S. (Denison and Ruston, 1995, 236).

Prior to 1991, the U.S. Air Force (USAF) had no formal policy guidance for municipal solid waste diversion or recycling (McDermott, 1991:15). Since then, the USAF has made MSW recycling and diversion a priority along with the rest of the federal government. Subsequent to the Pollution Prevention Act of 1990 and Executive Order 12856, "Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements," the USAF established the Air Force Pollution Prevention Program in 1993 (Department of the Air Force, 1994). Air Force Instruction (AFI) 32-7080, "Pollution Prevention Program," outlines program requirements, establishes a hierarchy of actions to prevent pollution, and mandates that the actions must be fully integrated into day-to-day operations. The USAF hierarchy is as follows: reduce/eliminate waste streams, reuse generated waste and recycle waste that is not reusable, employ treatment, and dispose of waste only as a last resort (Department of the Air Force, 1994: 5). In addition, the AFI instructs installations to integrate cost-effective waste reduction and recycling programs into their municipal solid waste management program and mandated

waste reduction goals, based on a 1992 baseline, of 30 percent by 31 Dec 96 and 50 percent by 31 Dec 97 (Department of the Air Force, 1994: 9, 13).

The USAF met the 50 percent goal in 1997 and reduced waste even further in 1998, achieving 56 percent reduction from the 1992 baseline (HQ USAF/ILEV, 1999b). Since meeting these goals, the USAF established new goals that are based on the percent of total waste diverted from landfill and incineration disposal instead of a baseline year (HQ USAF/ILEV, 1999a). The revised diversion goals by fiscal year (FY) are: 15 percent by 1999, 20 percent by 2000, 25 percent by 2001, 30 percent by 2002, 35 percent by 2003, and 40 percent by 2004 and 2005. These diversion efforts must break even by FY2004 and show an economic benefit by FY2005.

Driven by USAF pollution prevention policy and goals, most USAF installations worldwide have devised integrated solid waste management plans and continue to refine these plans as they strive to meet the latest USAF goals. However, there are still a few small USAF installations, particularly in remote Alaska, that do not take an integrated approach to MSW management yet and continue to landfill all MSW. Eareckson Air Station (AS), located 1,500 miles southwest of Anchorage, Alaska, on Shemya Island in the Aleutian chain of Alaska, is one of these installations (611 ASG, 1999).

Eareckson AS, in spite of disposing 100 percent of its MSW in a landfill owned and operated by the site, far exceeded the Air Force's first set of MSW goals. In 1998, Eareckson AS reported 88 percent waste reduction versus the 1992 baseline (611 ASG, 1999). However, when the latest AF MSW goals based upon percentage waste diversion went into effect in 1999, Eareckson reported zero percentage waste diversion for 1999 (611 ASG, 1999). Eareckson's initial success with the waste reduction goals can mostly

be attributed to the large drawdown in mission and personnel the installation experienced after the goals went into effect. When the 1992 baseline was established, Eareckson was a fully operational air base with about 700 military and civilian personnel (Jacobs, 1995). Currently, approximately 116 personnel reside at the installation, mostly base operations support (BOS) contractor personnel (PACAF, 2000). The latest goals, however, measure percentage waste diversion from landfill and incinerator disposal facilities for a particular year based upon the amount of waste generated in that year. Thus, by landfilling all of its MSW, Eareckson will not be able to achieve any of these goals unless an integrated approach to MSW management is taken.

While achieving AF waste diversion goals economically may be one reason for Eareckson to evaluate its current MSW practices, environmental compliance is the primary driver. Prior to April 2000, the Eareckson AS landfill was in full environmental compliance with state and federal solid waste management regulations. Classified as a small landfill owner/operator, Eareckson qualified for exemptions from some of the costlier federal and state landfill regulatory requirements, such as the requirements for a landfill liner and a leachate collection system. However, the Eareckson landfill no longer qualifies for these regulatory exemptions according to the Alaska Department of Environmental Conservation (ADEC) because groundwater contamination was detected beneath the landfill (ADEC, 2000b). Consequently, ADEC placed the Eareckson AS landfill in a non-compliance status and notified the Air Force of possible regulatory action if this problem is not remedied. To solve the site's current MSW woes, the MSW decision-maker for Eareckson must devise and implement a new environmentally

compliant strategy for integrated management and disposal of the installation's MSW (McCloud, 2000).

Developing and implementing an ISWM strategy is a local activity involving the selection of the proper mix of techniques and technologies to meet local waste management needs (USEPA, 1989). Each community has its own unique goals and constraints it must contend with when making this decision and there are several waste management alternatives from which to choose. There is no boilerplate solution to the problem of how a community should best manage its MSW.

1.2 Research Problem

The decision-maker at Eareckson Air Station requires a decision making tool that captures all of the site's MSW goals, objectives, and concerns to facilitate the evaluation of all MSW management strategies available and resulting in the selection of the best strategy for Eareckson.

1.3 Research Objective

The ultimate objective of this research effort is to develop a multiple-objective decision analysis model based upon the hierarchy of waste management objectives expressed by the decision-maker at Eareckson Air Station. This model will help provide insight to the decision-maker as to which solid waste management strategy is best suited for Eareckson's disposal needs.

1.4 Research Question

Since the Air Force will continue to generate MSW at Eareckson Air Station and must manage it in accordance with the law, the central question of this research is: Which combination of suitable waste management techniques, technologies, and programs is best suited to meet Eareckson's overall MSW goals and is consistent with the decision-maker's objectives and concerns regarding MSW management?

1.5 Research Approach

To answer the general research question and achieve the research objective, the following research approach will be taken.

1. Perform a review of current solid waste management literature to identify the key factors that must be considered in developing an effective ISWM strategy and to identify current ISWM techniques and technologies.

2. Conduct a review of Air Force, federal, and state policies and regulations that pertain to managing municipal solid waste to determine Eareckson AS's regulatory environment. This review will identify the minimal regulatory requirements that must be complied with by any new MSW system at Eareckson.

3. Employ multi-objective decision analysis (MODA) techniques in order to develop a quantitative multi-objective decision analysis model based on the objectives expressed by the decision-maker at Eareckson Air Station. The model will be used to evaluate how well alternatives meet these objectives and to provide insight to the decision-maker as to which alternative is best suited for Eareckson's MSW management needs.

Chapter 2. Literature Review

The purpose of this chapter is to provide background and frame the problem area for this research effort. First, it will provide an overview of the fundamentals of municipal solid waste (MSW). Second, it will provide background on Eareckson Air Station (AS), Alaska, location of the problem for this thesis effort. Third, Eareckson's MSW regulatory and policy environment will be discussed. Fourth, current MSW management alternatives for Eareckson will be summarized. Fifth, decision analysis is introduced as well as value-focused thinking, a multiple-objective decision making technique. Finally, the framework for the methodology used in this research effort is outlined.

2.1 Fundamentals of MSW

The following section discusses the fundamentals of MSW relevant to this research effort. After the definition, components, and characteristics of MSW are presented, integrated solid waste management and waste stream characterization are discussed.

2.1.1 Definition of MSW. MSW, often referred to as "garbage" or "trash," is a subset of solid waste and consists of durable goods, nondurable goods, containers and packaging, food wastes, yard trimmings, and miscellaneous inorganic wastes (USEPA, 1999a: 20). As illustrated by Figure 1, MSW does not include municipal sludges, construction and demolition debris, industrial process wastes, agricultural solid wastes, mining wastes, or regulated hazardous wastes.

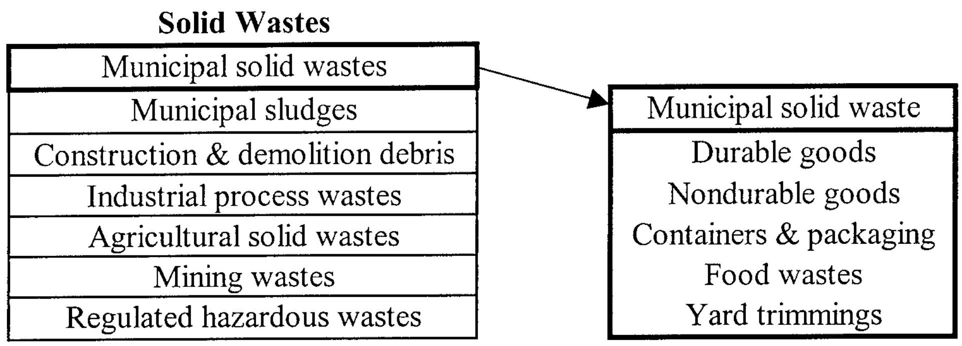


Figure 1. Types of Solid Wastes (USEPA, 1999a: 21)

2.1.2 MSW Components. Table 1 lists the components that most often comprise MSW as well as the percentage composition by weight; however, the heterogeneous nature of MSW makes it difficult to determine the exact composition. MSW composition typically varies with geographic location, seasons of the year, economic conditions, and many other factors (Tchobanaglous *et al.*, 1993: 45).

Table 1. Typical Components of MSW

Waste Component	% Composition by Weight
Paper and Paperboard	31.3
Food Wastes	13.6
Plastics	13.0
Yard Trimmings	10.4
Wood	7.0
Metals	6.5
Glass	6.3
Textiles	4.6
Rubber & Leather	3.7
Other	3.6

(USEPA, 1999a: 31)

2.1.3 Integrated Solid Waste Management Strategy. In a 1989 report, "The Solid Waste Dilemma: An Agenda for Action," the EPA presented its integrated solid waste management strategy to address the nation's increasing waste generation trend (USEPA, 1989). Integrated solid waste management (ISWM) refers to "the complementary use of a variety of waste management practices to safely and effectively handle the municipal solid waste stream with the least adverse impact on human health and the environment" (USEPA, 1989: 1). Figure 2 illustrates the components of the EPA strategy (source reduction, recycling, waste combustion, and land disposal) in EPA's preferred rank order (hierarchy).

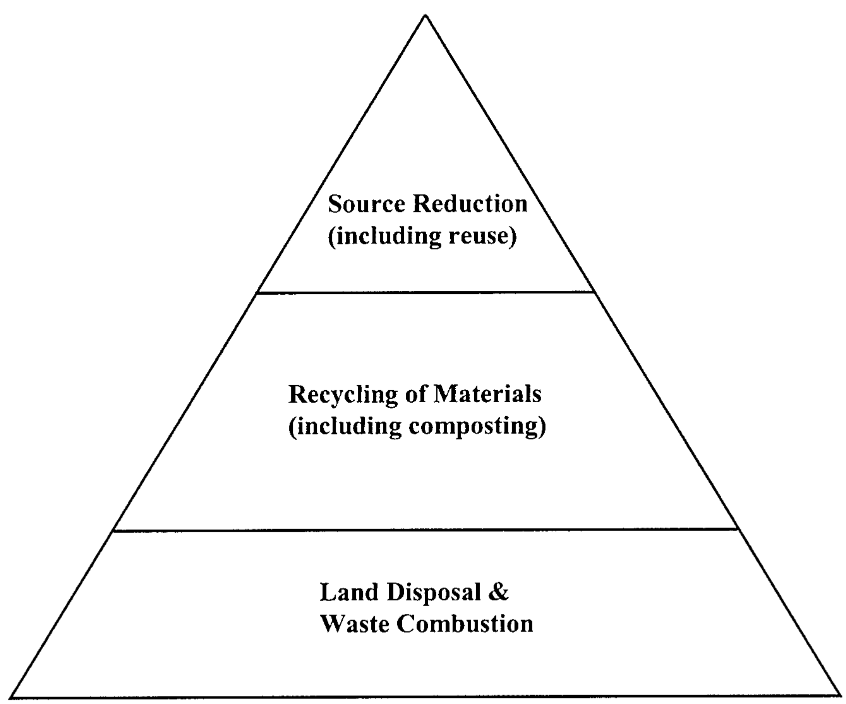


Figure 2. EPA's ISWM Hierarchy (USEPA, 1989)

Source reduction, also referred to as waste minimization, tops the hierarchy because of its potential to prevent pollution, consume fewer resources, reduce system costs, and increase efficiency. The second tier of recycling involves collecting materials, reprocessing/remanufacturing, and using the resulting end products. Recycling, which includes composting, can reduce the depletion of landfill space, save natural resources, provide useful products, and provide economic benefits. Finally, waste combustion and landfilling are at the bottom of the hierarchy. EPA does not rank one of these options higher than the other because both are considered viable components of an integrated system (USEPA, 1995: xxvii). Waste combustion reduces the volume and weight of municipal solid waste and can provide an added benefit of energy production. Landfills, on the other hand, will always be part of an ISWM system since there will always be non-recyclable and non-combustible waste to manage.

2.1.4 Characteristics of MSW. Each component of MSW has distinct physical, chemical, and biological properties that are pertinent to the development and design of an integrated solid waste management system. These properties are used to properly size MSW equipment and disposal facilities as well as to determine which transformation processes are feasible and most practical for a particular component in the waste stream. Transformation processes are used to reduce the volume and weight of wastes requiring disposal and to recover conversion products and energy. The most commonly used physical transformation processes are compaction and shredding while combustion and aerobic composting are the most common chemical and biological transformation processes, respectively (Tchobanaglous *et al.*, 1993: 90-95). The following is a summary of the physical, chemical, and biological properties important to this research effort.

2.1.4.1 Physical Properties. Two important physical characteristics of MSW are specific weight and moisture content. Specific weight, defined as the weight of a material per unit volume, is useful when assessing the total mass and volume of MSW that must be managed. The mass and volume of MSW is a key design factor for properly sizing MSW storage, collection, and processing equipment as well as transformation and disposal facilities. One must be careful when using specific weight data, however, because the specific weight of a waste component varies with the degree of compaction and moisture content. For example, it may only take 350 lbs of loose, moist green grass clippings to occupy 1 yd^3; but compacted, wet green grass clippings may be compressed to 1,400 lbs/yd^3 (Tchobanoglous *et al.*, 1993: 70). In the U.S., moisture content of MSW "as collected" varies from 15 to 40 percent, depending on the waste composition, geographic location, weather conditions, and season of the year (Tchobanoglous *et al.*, 1993: 72). Table 2 provides ranges and typical values for both specific weight and moisture content of several types of wastes.

Table 2. Specific Weight and Moisture Content of Various MSW Components

Type of Waste	Specific weight, lb/yd^3 Low	High	Typical	Moisture content, percent by weight Low	High	Typical
Residential (uncompacted)						
Food wastes (mixed)	220	810	490	50	80	70
Paper	70	220	150	4	10	6
Cardboard	70	125	85	4	8	5
Plastics	70	220	110	1	4	2
Textiles	70	170	110	6	15	10
Rubber	170	340	220	1	4	2
Leather	170	440	270	8	12	10
Yard Wastes	100	380	170	30	80	60
Wood	220	540	400	15	40	20
Glass	270	810	330	1	4	2
Steel Cans	85	270	150	2	4	2
Aluminum	110	405	270	2	4	2
Other metals	220	1940	540	2	4	3
Dirt, ashes, etc.	540	1685	810	6	12	8
Incinerator Ashes	1095	1400	1255	6	12	6
Residential yard wastes						
Leaves (loose & dry)	50	250	100	20	40	30
Green grass (loose & moist)	350	500	400	40	80	60
Green grass (wet & compacted)	1000	1400	1000	50	90	80
Yard waste (composted)	450	600	500	20	70	50
Municipal						
In compactor truck	300	760	500	15	40	20
In landfill						
Normally compacted	610	840	760	15	40	25
Well compacted	995	1250	1010	15	40	25

(Tchobanoglous *et al.*, 1993: 70)

2.1.4.2 Chemical Properties. The chemical composition of each MSW component is important in evaluating both chemical and biological transformation processes. Three significant evaluation parameters determined by chemical composition are energy content, inert ash residue, and carbon-to-nitrogen (C:N) ratio.

The first two parameters, energy content and inert ash residue, are often used as screening criteria to determine whether a particular waste component should be combusted. Waste components that are low in energy content and high in inert ash residue, such as glass and metals, are considered to be non-combustible and combustion is not a feasible transformation process for these wastes. In addition, energy content is also a critical design criterion when designing a new incinerator facility. The expected typical energy content of the waste to be processed is vital to the selection of the thermal processing system, which impacts the physical size of the facility (Tchobanoglous *et al.*, 1993: 625). Furthermore, inert waste residue, which represents how much waste remains after combustion, is used to calculate the amount of waste requiring further disposal in a landfill after combustion. Table 3 provides typical values for inert residue and energy content of MSW.

Table 3. Typical Values for Inert Residue and Energy Content of MSW

Component	Inert residue, percent			Energy, Btu/lb		
	Low	High	Typical	Low	High	Typical
Organic						
Food wastes	2	8	5	1500	3000	2000
Paper	4	8	6	5000	8000	7200
Cardboard	3	6	5	6000	7500	7000
Plastics	6	20	10	12000	16000	14000
Textiles	2	4	2.5	6500	8000	7500
Rubber	8	20	10	9000	12000	10000
Leather	8	20	10	6500	8500	7500
Yard wastes	2	6	4.5	1000	8000	2800
Wood	0.6	2	1.5	7500	8500	8000
Inorganic						
Glass	96	99	98	50	100	60
Steel Cans	96	99	98	100	500	300
Aluminum	90	99	96	0	0	0
Other metals	94	99	98	100	500	300
Dirt, ashes, etc.	60	80	70	1000	5000	3000

(Tchobanoglous *et al.*, 1993: 84)

The third parameter, C:N ratio, is used as a screening criterion to determine which waste components or mixture of waste components can be effectively composted. As a general rule of thumb, the C:N ratio for compost should be between 25:1 and 35:1 and the moisture content about 55 percent for the composting process to most optimally work (AFCEE, 1995: 2-xix). The composting process slows considerably at C:N ratios greater than 35:1 and less than 25:1 (AFCEE, 1995: 3-xx). In the later case, anaerobic conditions form creating an odor nuisance. Table 4 provides the C:N ratios of selected compostable materials. Blending of wastes high in carbon and low in nitrogen (e.g., mixed paper) with a waste that is high in nitrogen (e.g., yard wastes) is used to achieve optimum C:N ratios for composting .

Table 4. Typical C:N Ratios of Selected Organic Materials

Component	C:N Ratio
Food Wastes	15:1
Yard Wastes	20:1
Mixed Paper	173:1
Wood	700:1

(AFCEE, 1995:3-xx)

2.1.4.3 Biological Properties. The biological properties of each MSW component determine whether the component is biodegradable. Components that are biodegradable are considered to be "organic" while those that do not biodegrade are "inorganic." Perhaps the most important biological characteristic of MSW is that almost all of the organic components can be transformed biologically to gases and relatively inert organic or inorganic solids, thereby effectively reducing the original weight and volume of the waste (Tchobanoglous *et al.*, 1993: 88). Most of the organic fraction of MSW may be used as feedstock for the production of biological conversion products like compost. In the U.S., MSW contains up to 67 percent by weight of organic materials (USEPA, 1999b: 1).

2.1.5 Characterizing the MSW Stream. Reliable data on the quantity and composition of the MSW stream to be managed is required to properly analyze the available waste management techniques and technologies. Without a good idea of the quantities that can be expected, decisions about equipment and space needs, facilities, markets, and personnel cannot be reliably made (USEPA, 1995: 3-4). Furthermore, the composition of the solid waste stream is important for assessing potential environmental impacts associated with the different disposal options (Lund, 1993: 3.2).

Characterizing the quantity and composition of MSW material may be accomplished by modeling, direct measurement, or sampling techniques. The least expensive and quickest method is the modeling technique, which uses community population data and generic waste generation data found in the literature (USEPA, 1999a: 12; Lund, 1993: 3.29; Tchobanoglous *et al.*, 1993: 70). However, projections using average rates should not be used for planning specific facilities because inaccuracies in waste composition data can severely and negatively impact the economic viability of a waste management program (USEPA, 1995: 3-4). The most accurate and costly of the techniques is the direct measurement technique. This technique uses a bar-code system to help determine the weight and types of material collected. Communities with volume-based fee systems often use bar-code monitoring for billing purposes (USEPA, 1995: 3-9). Finally, the most widely used technique is the sampling technique. Sampling uses statistical methods to estimate waste stream composition and quantity from a representative, random sample of the waste stream. Several authors give an overview of the statistics and methodology used in sampling solid waste (Stessel, 1996: ch 2; Lund, 1993, ch 3). Furthermore, the American Society for Testing and Materials (ASTM) approved a standard in July 1992 that describes procedures for measuring the composition of unprocessed MSW by using manual sorting (ASTM, 1992: 1).

2.2 Eareckson Air Station

Since this research effort is concerned with the MSW management system at Eareckson Air Station (AS), Alaska, this section provides a brief background of the military mission, location, and physical setting of the installation. In addition, Eareckson's current MSW system is discussed.

2.2.1 Military Mission. Eareckson Air Station is owned and operated by the 611 Air Support Group (ASG), which is headquartered at Elmendorf Air Force Base (AFB), Anchorage, Alaska. The mission of the 611 ASG is to provide communication, engineering, environmental, logistics, financial, and program management support to maintain combat readiness in remote areas of Alaska (611 ASG, 1998). The 611 ASG operates Eareckson AS through a Base Operations Support (BOS) contract. The BOS contractor is required to operate and maintain the active buildings, utilities, and other infrastructure, such as the roads and a 10,000-foot runway, in support of the military mission of Eareckson AS. The current mission of Eareckson AS is to support (1) en route aircraft, (2) early warning radar surveillance, and (3) Department of Defense communications (611 ASG, 1998).

2.2.2 Location. Eareckson AS occupies the entire island of Shemya, located 1,500 miles southwest of Anchorage (Figure 3). This island is a member of the Semichi group of the Near Islands, a part of the Aleutian Chain in Alaska. Shemya Island is only 2.5 miles wide and 4.5 miles long, with a total area of 3,200 acres (Eareckson AS, 1994).

Figure 3. Location of Eareckson AS, Alaska

2.2.3 Physical Setting. Shemya Island is a relatively flat-topped seamount of volcanic origin. The highest point is approximately 300 feet above mean sea level. The majority of the island's perimeter consists of steep bedrock cliffs and gravel beaches. Several small ponds dot the island's surface. Trees are not present on Shemya and the predominant vegetation consists of low-lying tundra species. Frequent storms, overcast skies, dense fogs, and high winds are common on Shemya. Consistently strong winds may blow from every direction with an average wind speed of 17 knots. Temperatures average in the 40°F range during the summer and in the 30°F range during the winter; there are relatively few freezing days and freezing weather is generally of short duration. Shemya receives an annual average of 30.6 inches of precipitation. (Eareckson AS, 1994: 2-5)

2.2.4 Current MSW Management System. The activities associated with the management of MSW at Eareckson AS can be grouped into five functional elements: administration, generation, storage, collection, and disposal.

2.2.4.1 Administration. The MSW management system at Eareckson is operated and maintained by the BOS contractor. Engineering support, design, and planning are provided by the 611 Civil Engineer Squadron (CES) environmental flight.

2.2.4.2 Generation. The last MSW generation survey conducted at Eareckson AS estimated that the site generated 952 tons of MSW in 1992 (Law Environmental, Inc., 1994) when the population was approximately 700 personnel (Jacobs, 1995). In late 1994, the Air Force began downsizing operations at the site. Currently, there are approximately 116 contractor and tenant unit personnel on site operating and maintaining 70 active facilities (PACAF, 2000). Unfortunately, no direct measured MSW generation data is available for Eareckson due to the fact the site no longer has a scale to weigh the waste collection vehicle. However, a July 2000 landfill site selection report estimated that the site generates 435 lbs per day (79 tons per year) based upon the current population and a generation rate of 3.75 pounds per person per day (ppd) (Jacobs, 2000).

2.2.4.3 Storage. All MSW generated at Eareckson AS is temporarily stored in 22 five-cubic-yard dumpsters situated throughout the installation until collection.

2.2.4.4 Collection. BOS contractor personnel empty the dumpsters approximately twice per week using a 24-cubic-yard front-loading trash collection truck

specifically designed to empty dumpsters. The waste is then transported to the Eareckson landfill for disposal.

2.2.4.5 Landfilling. The trash collection truck is emptied at the Eareckson AS landfill. The existing landfill is an unlined, open-area fill operation. Therefore, there is no leachate collection system. In addition, the landfill does not contain a gas monitoring system; however, there are groundwater monitoring wells. An adjacent borrow pit provides a source of cover material. The waste and cover material is compacted by driving a front-end loader over the newly deposited waste and cover. The Eareckson AS landfill has been operational since 1944 (Eareckson AS, 1994).

Figure 4 illustrates the current process of MSW management at Eareckson from generation to disposal. As one can see, once waste is generated, the only available management alternative is to dispose of it in the landfill.

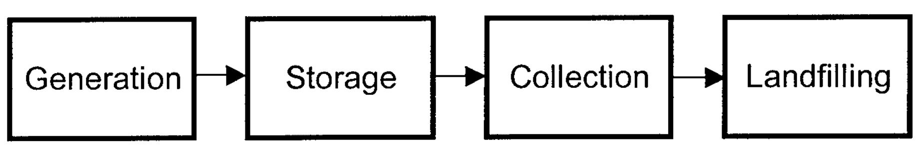


Figure 4. Eareckson AS MSW Management Process

2.3 MSW Regulatory and Policy Environment

Almost all facets of MSW are regulated from waste generation to disposal. Like any other community, Eareckson AS must comply with all federal, state, and local regulations pertaining to the management of MSW. In addition, as a federally owned facility, Eareckson AS must comply with all Department of Defense (DoD) and Air Force

policies and presidential executive orders as well. Regulations establish minimal standards that must be met, while executive orders and policies provide direction and guidance. These regulations, orders, and policies strongly shape and define which waste management alternatives are legally feasible and desirable for Eareckson AS. The following is a summary of the federal and state regulations, executive orders, and DoD and Air Force policies that apply to MSW disposal and pollution prevention at Eareckson AS. It is important to note that air and water quality issues are included along with solid waste regulatory requirements.

2.3.1 MSW Disposal Regulations. The EPA has developed a comprehensive set of federal regulations pursuant to the Solid Waste Disposal Act of 1965 and its 1970, 1976, and 1984 amendments that establish minimal national standards applicable to solid waste management. States are responsible for actually implementing and enforcing the standards with their own EPA-approved waste programs (USEPA, 1993: 4). States that apply for and receive EPA approval of their programs have the opportunity to provide a lot of flexibility in implementing the regulations. This flexibility allows states to take local conditions and needs into account, thereby making the costs of municipal solid waste management more affordable. In addition, states may establish requirements that are more stringent than those set by the federal government. The State of Alaska's solid waste program has received EPA approval.

2.3.1.1 Federal Disposal Requirements. Federal requirements for MSW disposal are primarily found in the Code of Federal Regulations (CFR), Title 40, Parts 258 and 240 (40 CFR 258 and 40 CFR 240). These regulations contain specific location, design, and operating criteria for thermal processing and land disposal facilities.

Minimal federal national standards for landfills are established by 40 CFR 258, "Criteria For Municipal Solid Waste Landfills," which covers the following seven basic areas: location, operation, design, groundwater monitoring, corrective action, closure and post-closure care, and financial assurance (CFR, 1999b). In addition, this portion of the CFR creates two classes of landfills: small landfills and all other landfills that do not meet the exemptions for a small landfill. The CFR exempts small landfills that are less likely to contaminate groundwater and pollute the air from some of the more costly requirements. To qualify, a landfill must receive less than 20 tons of waste per day (averaged yearly), receive less than 25 inches of rainfall per year, and have no other practical waste disposal alternative (USEPA, 1993: 6). In addition, there must not be any evidence of groundwater contamination from the landfill. Extremely remote communities that have no ready access to other disposal sites for extended periods of time are also eligible for an exemption (USEPA, 1993: 6).

Minimal federal national standards for incinerator facilities are established by 40 CFR 240, "Guidelines for the Thermal Processing of Solid Wastes," which applies to thermal processing facilities designed to process or which are processing 50 tons or more per day of MSW. Since Eareckson only generates an estimated 79 tons of MSW per year (Jacobs, 2000), this portion of the CFR would not apply to Eareckson if it were to construct an incinerator facility.

2.3.1.2 State Disposal Requirements. Alaska Administrative Code (AAC), Title 18, Chapter 60 (18 AAC 60), "Solid Waste Management," contains the minimal state criteria for municipal solid waste landfills in Alaska. For the most part, 18 AAC 60 has adopted the same minimal criteria contained in all seven of the basic

areas covered by federal regulations. Standards for what Alaska considers Class II and Class I municipal solid waste landfills (MSWLFs) are the same as those standards set forth in 40 CFR 258 for small landfills and all other landfills that do not meet the exemptions for a small landfill, respectively. However, 18 AAC 60 significantly differs from federal standards by defining a third type of landfill called a Class III MSWLF for which the standards are actually less than the minimal federal standards in some instances. For example, the owner of a Class III MSWLF does not have to perform methane gas monitoring unless ADEC directs so while Class I and Class II landfill owners are required to perform routine methane gas monitoring (ADEC, 1999: 43). As another example, Class III landfill owners are only required to perform 5 years of post-closure care as opposed to 30 years for Class I and Class II landfills (ADEC, 1999: 59). While these examples are just two of many, they serve to illustrate how reduced requirements for Class III landfills can result in significant operational cost savings.

Until December 1999, Eareckson AS's landfill was classified as a Class III landfill by ADEC. The latest revision of 18 AAC 60, however, now disqualifies Eareckson from Class III eligibility. The regulation now specifically prohibits Class III status at facilities "(i) where public access is restricted, including restrictions on the right to move to the place and reside there; or (ii) that is provided by an employer and that is populated totally by persons who are required to reside there as a condition of employment and who do not consider the place to be their permanent residence" (ADEC, 1999: 42). However, Eareckson can qualify for Class III status if the facility incinerates all combustible waste (ADEC, 1999: 42).

2.3.2 Air Emissions Regulations Related to MSW Management. Using the authority of the Clean Air Act (CAA) of 1955 and its numerous amendments (the CAA has been amended 20 times through 1991), the EPA has issued a number of regulations to control emissions from solid waste management facilities, particularly MSW combustors (incinerators) and MSWLFs (Hickman, 1999: 26).

2.3.2.1 Federal Air Emissions Requirements. Federal requirements for landfill gas emissions and MSW combustor emissions are found in 40 CFR 60, "Standards of Performance for New Stationary Sources." 40 CFR 60, Subpart Eb contains the performance standards for municipal waste combustors for which construction is commenced after September 20, 1994. This subpart only applies to facilities with a combustion capacity greater than 250 tons per day of municipal solid waste (CFR, 1999a). These standards address emission limits on organics, acid gases, metals, and nitrogen oxides (Hickman, 1999: 26). 40 CFR 60, Subpart WWW regulates landfill gas emissions from all new and existing MSWLFs with a maximum design capacity of 2.75 million metric tons (2.5 million cubic meters) (Hickman, 1999: 26). Subpart WWW also requires MSWLFs with nonmethane organic compound (NMOC) emission rates of 50 megagrams per year or more to install landfill gas collection and control systems to reduce NMOC emissions (CFR, 1999a).

2.3.2.2 State Air Emissions Requirements. State requirements for landfill gas emissions and MSW combustor emissions are found in 18 AAC 50, "Air Quality Control." Alaska has adopted 40 CFR 60 by reference except for the standards for opacity and particulate matter; the EPA has approved less stringent standards for Alaska in these two areas. For opacity, visibility through the exhaust effluent of an

incinerator may not be reduced by more than 20 percent for a total of no more than three minutes in any one hour (ADEC, 2000a: 19). The federal emission limit for opacity exhibited by the gases discharged to the atmosphere from a MSW combustor facility is 10 percent using a six minute average (CFR, 1999a: 144). For particulate matter, the federal standard specifies that a facility shall not discharge into the atmosphere any gases that contain particulate matter in excess of 24 milligrams per dry standard cubic meter, corrected to 7 percent oxygen. The Alaskan standards, which vary according to the size of the incinerator, are shown in Table 5.

Table 5. Particulate Matter Standards for Incinerators

Incinerator	Particulate Matter Standard
Rated capacity less than 1000 pounds per hour	No limit
Rated capacity greater than or equal to 1000 but less than 2000 pounds per hour	0.15 grains per cubic foot of exhaust gas corrected to 12 percent CO_2 and standard conditions, averaged over three hours
Rated capacity greater than or equal to 2000 pounds per hour	0.08 grains per cubic foot of exhaust gas corrected to 12 percent CO_2 and standard conditions, averaged over three hours
An incinerator that burns waste containing more than 10 percent wastewater treatment plant sludge by dry weight from a municipal wastewater treatment plant that serves 10,000 or more persons	0.65 grams per kilogram of dry sludge input

(ADEC, 2000a: 19)

Currently, Eareckson AS does not have an incinerator facility and any future landfills will most certainly be less than 2.75 million metric tons. Thus, the regulations for MSW combustor emissions and landfill gas emissions do not apply to Eareckson. Even if Eareckson were to construct an incinerator facility, the MSW combustor

regulations would not apply because the combustion capacity would most likely be less than 1000 pounds per hour. However, this does not exempt Eareckson from the prevention of significant air quality deterioration (PSD) review process and federal PSD permit requirements. Obtaining a PSD permit, a lengthy process at this time, requires an accurate analysis of the existing air quality and the potential impacts of the proposed facility (Dalcher, 2000). Since Eareckson is located within an "attainment area" for air quality, a new source review (NSR) permit is not required (Dalcher, 2000).

2.3.3 MSW Pollution Prevention Regulations and Policies. The federal government's desire to reduce waste and recycle dates back to the Solid Waste Disposal Act of 1965. However, it wasn't until the passage of the Pollution Prevention Act (PPA) of 1990 that source reduction and recycling really became part of daily operations within federal agencies such as the Air Force. The Pollution Prevention Act (PPA) of 1990 shifted the focus of environmental protection from "end-of-pipe" treatment to "front-of-pipe" source reduction.

2.3.3.1 Federal MSW Pollution Prevention Regulations. Source separation for the purpose of resource recovery as established by 40 CFR 246, "Source Separation for Materials Recovery Guidelines," is mandatory for all federal facilities that generate solid waste (CFR, 1998). 40 CFR 246 establishes minimum actions that federal agencies must take and provides recommended procedures for recovery of high-grade office paper, cardboard, mixed paper, glass, and cans (CFR, 1998). However it provides exclusions for small facilities, such as Eareckson AS, that are only required to investigate materials recovery and recycling and implement where feasible (CFR, 1998).

2.3.3.2 MSW Pollution Prevention Related Executive Orders. As a federal agency that is part of the executive branch of the U.S. government, the Air Force must comply with presidential Executive Orders (EOs). Three particular executive orders (EO12856, EO12873, and EO13101) over the past decade have had a significant impact on the Air Force Pollution Prevention Program.

By issuing EO12856, "Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements," the President directed all executive agencies of the federal government to support the PPA (Clinton, 1993a). The EO mandated that each agency develop pollution prevention (P2) goals and strategies for reducing hazardous materials use, waste production, and energy consumption (Clinton, 1993a).

By issuing, EO12873, "Federal Acquisition, Recycling, and Waste Prevention," the President directed all executive agencies to incorporate waste prevention and recycling in daily operations and to work to increase and expand markets for recovered materials through greater federal government preference and demand for such products (Clinton, 1993b). In addition, the EO orders each agency to establish goals for both solid waste prevention and recycling to be achieved by the year 1995 (Clinton, 1993b).

In an effort to further improve the federal government's use of recycled products and environmentally preferable products and services, the President issued EO13101, "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition." The overall priorities and direction given by EO13101 are very similar to EO12873, i.e., incorporating waste prevention and recycling in daily operations and working to create and expand recycling markets. However, EO13101 further mandates that each executive agency establish solid waste diversion short-range goals to be

achieved by January 1, 2000, and long-range goals to be achieved by the years 2005 and 2010 (Clinton, 1998).

2.3.3.3 Air Force Pollution Prevention Policy. Subsequent to the Pollution Prevention Act of 1990 and EO12856, the USAF established the Air Force Pollution Prevention Program in 1993 (Department of the Air Force, 1994). Air Force Instruction (AFI) 32-7080, "Pollution Prevention Program," outlines program requirements, establishes a hierarchy of actions to prevent pollution, and mandates that the actions must be fully integrated into day-to-day operations. The USAF hierarchy is as follows: reduce/eliminate waste streams, reuse generated waste and recycle waste that is not reusable, employ treatment, and dispose of waste only as a last resort (Department of the Air Force, 1994: 5).

In response to EO13101, the Deputy Undersecretary of Defense (Environmental Security) issued a policy memorandum establishing the current DoD Non-Hazardous Solid Waste Diversion Rate Measures of Merit (MoM). The memorandum states: "By the end of FY2005, ensure the diversion rate for non-hazardous solid waste is greater than 40%, while ensuring integrated non-hazardous solid waste management programs provide an economic benefit when compared with disposal using landfilling and incineration alone" (Goodman, 1998). As a result of this memorandum, the Air Force established the non-hazardous solid waste diversion rate goals shown in Table 6 and deadlines by which these programs should break even and show an economic benefit.

Table 6. Air Force Waste Diversion Goals

Fiscal Year	Diversion Rate (%)	Economic Benefit
1999	15	N/A
2000	20	N/A
2001	25	N/A
2002	30	N/A
2003	35	N/A
2004	40	Break Even Point
2005	40	Economic Benefit

(HQ USAF/ILEV, 1999a)

2.4 MSW Management Alternatives

There are presently four primary management techniques for handling MSW: recycling, composting, incineration, and landfilling. Recycling is the process by which materials otherwise destined for disposal are collected, processed, and remanufactured or reused (Lund, 1993: 1.1). Composting is a biological process of stabilizing organic matter under controlled conditions into a product that is rich in humus and provides organic matter and nutrients (USEPA, 1999b: 1). Incineration is a controlled process by which combustible solid, liquid, or gaseous wastes are burned and changed into noncombustible gases and ashes (CFR, 1999a). Finally, landfilling provides environmentally sound disposal of waste that cannot be or are not recycled, composted, incinerated, or processed in some other manner (USEPA, 1995: 9-2).

As discussed earlier in this chapter, each component of MSW has distinct physical, chemical, and biological properties. These properties help determine which physical, chemical, and biological transformations are feasible for each component and which transformations should be used to improve the efficiency of a solid waste

management system. In other words, the four primary management techniques for handling MSW do not always work for each component. For example, an aluminum can may be recycled since there is a market for this type of material and it may be disposed in a landfill as well. It cannot be composted or incinerated since it is non-biodegradable and non-combustible.

Each of the four waste management techniques has several alternative technologies or management choices, expanding the number of potential waste management alternatives for each component. The following section provides a brief discussion of the four MSW management techniques and the alternative technologies and management choices for each technique summarized in Table 7.

Table 7. Summary of Waste Management Alternatives By Primary Technique

Landfills	Recycling	Composting	Incineration
Class I MSWLF	Glass	Verniculture	Modular
Class II MSWLF	Newspapers	Windrow	Mass-Burn
Class II MSWLF without liner and leachate collection	PET Plastic	Aerated Static Pile	RDF
Class III MSWLF	HDPE Plastic	In-Vessel	None
	Aluminum	None	
	Cardboard		
	Steel Cans		
	Office Paper		
	None		

2.4.1 Recycling Alternatives. Designing an efficient recycling program involves decisions about which materials to recycle, method of collection and separation, and transportation of the recyclable material to market.

2.4.1.1 Materials. The list of potentially recyclable products is long and continues to grow as technological developments enable more products to be recycled and as markets for recyclable materials grow. The most commonly recycled materials are listed below (Aquino, 1995: 1-29).

- Glass containers
- Newspapers
- Polyethylene terephthalate (PET) bottles and containers
- Aluminum packaging
- High-density polyethylene (HDPE) bottles and containers
- Cardboard
- Steel cans
- Office paper

2.4.1.2 Collection and Separation. The most common methods for collecting recyclable materials are curbside collection in which a third party collects the recyclables and drop-off collection in which the waste generator delivers the materials to a recycling drop-off point. The most common separation methods are source separation in which the waste generator sorts the recyclables into homogenous components and processing facility separation, more commonly known as a materials recovery facility (MRF). An MRF typically processes a heterogeneous mixture of recyclables through a series of manual and mechanical separation devices to sort the materials into homogenous components. This research effort assumes Eareckson AS contractor personnel will source separate their waste within the facility it is generated by using blue recycling containers which refuse collection personnel will collect (McCloud, 2000).

2.4.1.3 Transportation. For most communities, trucking or rail are the most obvious solutions to transportation of recyclable materials to market. But for communities located on a remote island like Eareckson AS, these are not options. Airlift and barge are the only available means to transport cargo to and from Eareckson. Presently, only one barge travels to Eareckson per year (McCloud, 2000). Most cargo is transported by military C-130 aircraft and commercially contracted airlift at an average of three planes per week. These planes bring required supplies to the island and return to Elmendorf Air Force Base (AFB) in Anchorage, Alaska, mostly empty (McCloud, 2000). Therefore, the potential exists for using these return trips to transport recyclables to Elmendorf AFB on a space available basis. Elmendorf AFB contains a recycling center and a Defense Reutilization and Marketing Office (DRMO) that can transfer Eareckson's recyclables to Anchorage-area recycling centers (Paige, 2000).

2.4.2 Composting Alternatives. Composting can play an important role in an ISWM system since a majority of MSW is comprised of organic materials. Composting provides a means to recover the organic fraction of the waste stream to produce usable products such as mulch, soil conditioner, topsoil additive, and landfill cover material (USEPA, 1999b: 40). As with recycling, the decision to compost also involves making decisions about separation and collection. According to a recent pollution prevention opportunity assessment conducted at Eareckson AS, almost all of Eareckson's organic MSW is generated by the site's dining hall (Earth Tech, Inc., 1998). This research effort assumes this organic waste will be source-separated and collected appropriately (McCloud, 2000). Once collected, the waste may be treated using one of several different composting technologies, most of which fall into the following categories.

- Vermiculture
- Windrow
- Aerated static pile
- In-vessel

2.4.2.1 Vermiculture. Vermiculture compost systems are typically containerized and use various species of earthworms to help biodegrade the organic material. Earthworms eat all forms of food waste, yard and garden waste, and shredded paper and cardboard (EPM, Inc., 2000). Vermiculture units are small scale composting systems and each unit can only process about 20 lbs of food per day (EPM Inc., 2000).

2.4.2.2 Windrow. A windrow is a large elongated pile of composting material, triangular in cross section, which has a large exposed surface area to encourage passive aeration and drying (USEPA, 1995: 7-22). These piles are usually six to twenty feet wide, as high as twelve feet, and the length varies depending on space limitations (Hickman, 1999: 306). The windrows can exist either outside or in an enclosed facility. Turning or stirring the windrow with specialized equipment re-introduces air into the pile and increases porosity so that efficient passive aeration continues at all times. Complete composting with this method can take 6 to 8 weeks (Tchobanoglous *et al.*, 1993: 306).

2.4.2.3 Aerated Static Pile. As the name implies, the composting mixture for an aerated static pile is simply placed in a pile and is not turned like the windrow system. The pile is aerated using forced air running through tubes underneath the pile. Air circulation in the pile provides the required oxygen for composting microbes and also prevents excessive heat build-up in the pile. Typical pile heights are about seven to eight feet by fourteen to sixteen feet wide and are typically enclosed or covered

(Tchobanoglous *et al.*, 1993: 307). Producing compost using this technology usually takes 6 to 12 weeks (USEPA, 1995: 7-24).

2.4.2.4 In-vessel. In-vessel composting is accomplished inside a closed chamber or vessel that provides adequate mixing, aeration, and moisture. There are several different vessel configurations; drums, silos, tunnels, and digester bins are the most common. Plug flow systems work on a first-in, first-out principle while dynamic systems mechanically mix the composting material during processing. The detention time for in-vessel systems varies from 1 to 2 weeks along with a curing period of 4 to 12 weeks (Tchobanoglous *et al.*, 1993: 308). Some of the major benefits of in-vessel composting as opposed to other types of composting are listed below.

- Insulated vessel allows the composter to be used year round even in cold climates
- Mechanics of the system are very simple and easy to maintain
- Eliminates strong odors within days
- Material is isolated from the environment – no leaching or spillage
- Fastest type of composting available
- Flexibility regarding feedstock composition

2.4.3 Incineration Alternatives. According to the USEPA, U.S. municipal solid waste currently contains 36.7 percent combustibles (USEPA, 1999a: 5). Using incineration to capitalize on this relatively large amount of combustibles offers two primary benefits. First, incineration can be used to reduce the original volume of the combustible fraction of MSW by 85 to 95 percent (Tchobanoglous *et al.*, 1993: 291). Second, the heat produced during incineration may be used to produce steam and

electricity that can be marketed. The revenues generated from the sale of energy can help offset the operational costs involved with incinerating. Similar to recycling and composting, the decision to incinerate involves making decisions about separation and collection. This research effort assumes combustible wastes will be source-separated at each facility and collected by BOS contractor personnel (McCloud, 2000). Presently there are three primary types of technologies used for the incineration of solid waste as represented by the following systems.

- Starved air/modular systems which are primarily small combustion systems without the recovery of energy
- Mass-fired combustion systems
- Refuse derived fuel (RDF) fired combustion systems

2.4.3.1 Starved Air/Modular Systems. Starved air/modular combustion systems are usually small factory-assembled units consisting of a refractory-lined furnace. The units are predesigned, factory-fabricated modules shipped to the construction site for final assembly, which minimizes field installation time and cost. These units are small scale and normally range from 15 to 100 ton per day (tpd) in capacity (USEPA, 1995: 8-21). In general, modular combustor systems are the most cost effective combustion alternative for smaller-sized facilities (USEPA, 1995: 8-21).

Except for the removal of bulky items and hazardous solid wastes, modular systems burn solid waste as received with the combustion typically occurring in two stages. The first stage may be operated in "starved air," a condition in which there is less air than the theoretical amount necessary for complete combustion and results in the creation of volatile gases. During the second stage, these gases are fed into a secondary

chamber, mixed with additional combustion air, and completely burned under controlled conditions. The hot combustion gases may then be passed through a waste heat boiler for energy recovery purposes and/or processed through air emission control equipment. Modular systems differ from one another primarily in the method of solid waste movement through the combustion train. Some systems use various versions of a moving hearth or reciprocating grate system, while other systems use recessed hydraulic rams to advance the solid waste.

2.4.3.2 Mass-Fired Systems. Generally, mass-burn systems are more complex in design than modular facilities and are constructed on-site. Similar to modular systems, mass burn facilities burn solid waste as received, except for the removal of bulky items and hazardous solid wastes. A mass-burn facility typically consists of a reciprocating grate combustion system and a refractory-lined, water-walled steam generator for energy recovery (Hickman, 1999: 363). The rocking grate, rotary kiln, and roller grate combustion systems are used less frequently. Regardless of the type, each grate configuration is designed to tumble, turn, and move burning solid waste continuously through the furnace chamber while providing underfire air for maximum solid waste combustion. A typical mass-burn facility consists of two or more combustors with sizes ranging from 200 to 750 tons per day each (USEPA, 1995: 8-22).

2.4.3.3 RDF-Fired Systems. While modular and mass-fired systems receive, store, and fire MSW without preprocessing the waste, RDF-fired combustion systems preprocess and/or remove non-combustibles before feeding into the combustor. By removing non-combustibles, the waste burned by an RDF system has a higher energy content compared to unprocessed MSW. Thus, RDF combustion systems can be

physically smaller than comparatively rated mass-fired systems (Tchobanoglous *et al.*, 1993: 619). The dedicated combustor system is the most typical type of RDF-fired system (Tchobanoglous *et al.*, 1993: 619) and consists of a stoker-fed traveling grate and a water-wall steam generator. Unlike the mass-fired combustor, there is no refractory lining in the lower combustion zone of the combustor. The RDF is fired through an air-swept spreader above the traveling grate and is partially burned in suspension; larger and heavier particles are burned on the grate. The grate provides a platform on which the RDF can burn and provides for the introduction of under-fire air to promote turbulence and uniform combustion. RDF combustors range in size from 500 to 1500 tons per day (USEPA, 1995: 8-25). Fluidized bed combustion, co-firing RDF with coal or other biomass fuels, and densified RDF are other types of less frequently used systems.

2.4.4 Landfilling Alternatives. The backbone of a good solid waste management system is the landfill. For now, landfills will always be required for the environmentally sound disposal of waste that cannot be or is not recycled, composted, or incinerated. In addition, a landfill is needed for disposing of residues from recycling, composting, and incineration and can be used if alternative waste management facilities breakdown. According to State of Alaska regulation 18 AAC 60, Alaska's solid waste management regulation, there are three classifications of municipal solid waste landfills (MSWLFs) in the State of Alaska: Class I, Class II, and Class III. The following is a brief discussion of these three different MSWLF classifications.

2.4.4.1 Class I MSWLF. This landfill classification applies to any owner/operator of a landfill that accepts for disposal 20 tons or more per day and does not qualify as a Class II or Class III MSWLF (ADEC, 1999: 35). Of the three landfill

classifications, Class I MSWLFs have the strictest design and siting criteria and operational requirements.

2.4.4.2 Class II MSWLF. By qualifying as a Class II MSWLF, costly liner and leachate collection systems may be waived by the State, saving the owner/operator the expense of designing, constructing, operating, and maintaining these systems. 18 AAC 60 defines a Class II MSWLF as:

> a landfill that (A) accepts for disposal less than twenty tons pf MSW per day; (B) is located on a site where there is no evidence of groundwater pollution caused or contributed to by the landfill; (C) is not connected by road to a Class I MSWLF or, if connected by road, is located more than 50 miles from a Class I MSWLF; (D) and serves a community (i) that experiences for at least three months each year, an interruption in access to surface transportation, preventing access to a Class I MSWLF; or (ii) with no practicable waste management alternative, with a landfill located in an area that annually receives 25 inches or less of precipitation (ADEC, 1999: 40).

2.4.4.3 Class III MSWLF. Similar to a Class II MSWLF, qualification as a Class III MSWLF allows the State to waive the requirements for costly liner and leachate collection systems. Furthermore, operational requirements are significantly less stringent and post-closure care requirements are significantly less as well (5 years of post-closure monitoring as opposed to 30 years for Class I and Class II landfills). 18 AAC 60 defines a Class III MSWLF as:

> a landfill that is not connected by road to a Class I MSWLF or, if connected by road, is located more than 50 miles from a Class I MSWLF, and that accepts for disposal, (A) ash from incinerated municipal solid waste in quantities less than one ton daily on an annual average, which ash must be free of food scraps that might attract animals; or (B) less than five tons daily of municipal solid waste, based on an annual average, and is not in a place (i) where public access is restricted, including restrictions on the right to move to the place and reside there; or (ii) that is provided by an employer and that is populated totally by persons who are required to reside there as a condition of

employment and who do not consider the place to be their permanent residence (ADEC, 1999: 40).

2.5 Decision Analysis

Determining which combination of suitable waste management technologies is best suited to meet Eareckson Air Station's overall municipal solid waste (MSW) goals is very complex. There are numerous ways to manage Eareckson's MSW and each must be evaluated against multiple criteria: How much are operations and maintenance costs? What are the potential environmental impacts? Are Air Force waste diversion goals being met? These are just a few of the potential criteria a decision-maker may use to evaluate this problem. Given the number of MSW management alternatives and the multiple objectives they must be evaluated against, this problem is well suited for multiple-objective decision analysis techniques. This section begins by introducing decision analysis and exploring its application towards MSW decision-making. Next, a multiple-objective decision making technique used in this research, value-focused thinking, will be introduced. Finally, the framework that will be used to develop a decision support model for the Eareckson AS MSW problem will be discussed.

2.5.1 Introduction to Decision Analysis. Every decision-maker has cognitive limitations, or bounded rationality, preventing the consideration of every detail and uncertainty involved in a complex decision context. For this reason, a systematic procedure for transforming opaque decision problems into clear decision problems offers the decision-maker more focused insight and facilitates better decisions (Howard 1988: 680). Essentially, "decision analysis provides structure and guidance for thinking systematically about hard decisions" (Clemen, 1996: 2). Furthermore, Keeney and Raiffa

(1976: vii) describe decision analysis as a "prescriptive approach designed for normally intelligent people who want to think hard and systematically about some real important problems."

The scope of decision analysis is presented by Figure 5 in which an "X" is used to mark appropriate applications. As the figure shows, decision analysis is a prescriptive method designed for difficult decisions with complex structures. In addition, it can take into account uncertainty and the decision-makers' attitudes towards risk. Finally, decision analysis applies to decisions with either single or multiple, and potentially conflicting, objectives.

Once the scope of the application is established, decision analysis provides powerful techniques to aid decision-makers facing difficult choices. For example, it provides methods for structuring complex problems (decision trees, influence diagrams, objective hierarchies) that clearly show possible courses of action, the possible outcomes that may result, factors influencing and affected by such outcomes, and the eventual consequence that can occur from the different outcomes (Clemen, 1996: 2).

	Methodology	X
Descriptive		Prescriptive
	Decision Difficulty	X
Easy		Hard
	Problem Structure	X
Known/Simple		Unknown/Complex
X	**Problem Variables**	X
Deterministic		Unknown
X	**Objectives**	X
Single		Multiple
X	**Risk**	X
Low		Hgh

Figure 5. Scope of Decision Analysis (Kloeber, 2000)

2.5.2 General Application to MSW. MSW management problems are very difficult problems and can benefit from decision analysis techniques for several reasons. First, MSW management problems are often very complex due to the numerous alternatives, their possible combinations, and the resulting effectiveness of the combinations. Decision analysis can provide methods for structuring complex MSW problems to clearly show possible courses of action, the possible outcomes that may result, factors influencing and affected by such outcomes, and the eventual consequence that can occur from the different outcomes.

Second, decision analysis can address the inherent uncertainty associated with MSW management problems. Decision-makers rarely know the exact composition and quantity of MSW that a community will generate. In addition, the effectiveness of MSW technologies are often expressed in ranges based upon expert opinion. Decision analysis

can model these uncertainties and identify additional sources of uncertainty that can change the overall decision.

Third, decision analysis can aid MSW decision-makers in ranking alternatives based on multiple, but potentially conflicting, objectives. For example, waste diversion and saving resources are two valid MSW goals. Clearly, achieving the prior objective will likely have a negative impact on the latter objective. Decision analysis can provide a framework based upon multiattribute preference theory to address these multiple, conflicting objectives (Clemen, 1996: 3).

2.5.3 Specific Applications to MSW. Using decision analysis techniques to solve MSW related problems is not new. Over the past three decades, linear programming and related methods have been applied widely to different issues in MSW management, including optimization of collection routes (Liebman and Male, 1975; Marks and Stricker, 1971), site selection of transfer stations (Gottinger, 1986), and optimal cost schemes for regional solid waste management (Hasit and Warner, 1981).

More recently, research has dealt with optimizing integrated solid waste management systems. Lund (1990) presents a linear programming model which can be used to evaluate numerous recycling options as alternatives to landfilling or incineration. The model illustrates advantages that can result from implementing recycling programs and their impact on the service life of a landfill. Jacobs *et al.* (1993) present a model that optimizes scheduling of composting, recycling, and landfill operations in an ISWM system using cost as the sole optimization criteria. The model can aid community decision-makers in the long-term planning of future landfills and possible implementation of diversion programs. Barlaz *et al.* (1995a, 1995b) also propose a linear programming

model that minimizes cost. Their model is much more extensive than the Jacobs *et al.* model; in addition to composting, recycling, and landfill options, it takes into account incineration options and collection and separation alternatives as well. Huang *et al.* (1997) present a mixed integer linear programming model used to aid decision-makers in capacity planning for an ISWM system. Once again, cost minimization is the objective of the model. Chang *et al.* (1993) introduces a goal-programming model that optimizes both environmental and cost objectives of an ISWM system. The model can be used to allocate components of the waste stream to recycling, composting, incinerator, and landfill facilities in the most environmentally and economically acceptable method over a period of time, subject to financial, physical, and environmental constraints (Chang *et al.*, 1993: 88). Daskalopoulos *et al.* (1998) also use a goal-programming model that predicts the likely environmental and economic impacts that a particular MSW stream will have from one or a combination of waste treatment and disposal technologies.

A preliminary meeting with one of the Eareckson AS decision-maker's representatives indicated that minimizing resources and maximizing pollution prevention and protection of the environment (McCloud, 2000) are some, but not necessarily all, of the objectives in this decision situation. Clearly, a model that addresses multiple and conflicting objectives is required. Of the models previously discussed, the Chang *et al.* model is the most appropriate for this decision situation. However, even this elaborate model does not address all of the preliminary objectives. Therefore, a multiple-objective decision model that takes into account all of the Eareckson AS decision-maker's objectives must be developed.

2.5.4 Value Focused Thinking. Value-focused thinking (VFT) can be a very important process in decision situations where there are multiple, and potentially conflicting, objectives. The VFT method helps structure the decision-makers' values and goals so a decision analysis model can identify the alternatives providing the most value to the decision-makers. While value-focused thinking is not the usual approach to a decision situation, in many cases it provides a more effective approach capable of producing better results.

2.5.4.1 VFT Versus Alternative-Focused Thinking. "Value-focused thinking essentially consists of two activities: first deciding what you want and then figuring out how to get it" (Keeney, 1992: 4). This is opposed to alternative-focused thinking where alternatives are identified first and then objectives and criteria to evaluate them are considered. Almost all decision-makers solve problems using alternative-focused thinking (Keeney, 1992: 3); however, decision-makers must consider why they are making a decision in the first place. People make decisions hoping to maximize desirable outcomes and minimize undesirable outcomes. "The relative desirability of consequences is a concept based on values. Hence, the fundamental notion in decisionmaking should be values, not alternatives. Alternatives are the means to achieve the more fundamental values" (Keeney, 1992: 3).

2.5.4.2 Advantages of Value-Focused Thinking. In addition to creating alternatives, value-focused thinking can provide much more insight and information to the decision-maker. Figure 6 and the accompanying descriptions in Table 8 illustrate these advantages.

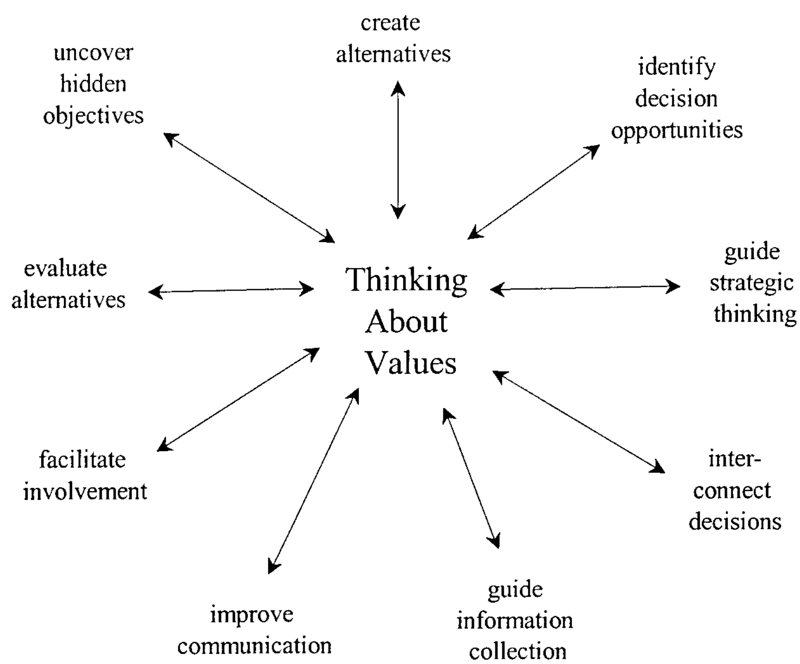


Figure 6. Overview of Value-Focused Thinking (Keeney, 1992: 24)

Table 8. **Advantages of Value-Focused Thinking**

Advantage	Description
Uncovering hidden objectives	Value-focused thinking includes a number of techniques that can be used to stimulate creativity in identifying possible objectives not yet realized.
Creating alternatives	Focusing on the values that should be guiding the decision makes the search for new alternatives a creative and productive exercise (Keeney, 1994: 39). Creating new alternatives may be more important than evaluating available alternatives.
Identifying decision opportunities	Decision situations should be viewed as opportunities to take advantage of and not as problems to solve. Systematically evaluating whether and how you can better achieve your values may create decision opportunities.
Guiding strategic thinking	Value-focused thinking compels the decision-maker to formulate strategic objectives.
Inter-connecting decisions	"Strategic objectives provide common guidance for all decisions in an organization and form the basis for more detailed fundamental objectives appropriate for specific decisions" (Keeney, 1994: 34).
Guiding information collection	When you know what is important to the decision situation, then you can be sure to collect information about the important objectives and not waste valuable resources collecting information about objectives that are not important.
Facilitating improvement in multiple-stakeholder decisions	Many decisions involve multiple stakeholders who have their own interests in the decision. Value-focused thinking helps to facilitate communications among the stakeholders regarding the important objectives for decision. "In situations with controversy, a common understanding about what are important [objectives] may provide a better basis for compromise and/or consensus with regard to selecting alternatives" (Kirkwood, 1997: 23).
Improving communication	Value-focused thinking uses a common vocabulary regarding the achievement of objectives in a particular decision context. This basis should help facilitate communication and understanding.
Evaluating alternatives	Value-focused thinking provides a framework for quantifying values, which allows one to construct a quantitative value model to evaluate various alternatives and rank them by total value. Sensitivity analysis of an alternative's desirability to a specific value may be conducted to provide the decision-maker powerful insight.

2.6 Decision Support Model Framework

This section discusses the ten steps that will be used to develop a decision support model for the Eareckson AS MSW problem. These steps were derived in part from the work of Keeney (1992), Kirkwood (1997), and Kloeber (2000) who discuss the value-focused thinking methodology for structuring and analyzing decisions in which multiple competing objectives require consideration of tradeoffs among the objectives.

2.6.1 Step 1 - Identify the Problem. The first and most important step in any decision situation is for the decision-maker to correctly identify the problem that needs to be solved. Incorrectly identifying the problem will often amount to nothing more than wasted effort, time, and money. Clemen (1996: 5) calls such a mistake an "error of the third kind."

2.6.2 Step 2 - Develop Objectives Hierarchy. The classical decision-making model lists "identify alternatives" as the second step in the decision making process once the problem has been identified (Griffin, 1999: 270). However, Keeney (1994: 33) disagrees with this approach because it is reactive rather than proactive and believes values should be the primary focus of decision-making. His explanation for identifying values (referred to as objectives the remainder of this document) at this step in the decision process is given below. Once the objectives have been determined, they are then structured in a hierarchical fashion.

> Values, as I use the term, are principles for evaluating the desirability of any possible alternatives or consequences. They define all that you care about in a specific decision situation. It is these values that are fundamentally important in any situation, more fundamental than alternatives, and they should be the driving force for our decision making. Alternatives are relevant only because they are a means to achieve values. Thus, although it is useful to iterate between articulating values and creating alternatives, the principle should be "values first." This manner

> of thinking, which I refer to as value-focused thinking, is a way to channel a critical resource-hard thinking-in order to make better decisions (Keeney, 1994: 33).

2.6.2.1 Generating Objectives. The determination of what objectives to use for the decision situation is ultimately made by the decision-maker. The following is a list of some of the techniques Keeney (1994: 35) suggests for generating the decision-maker's objectives. The questions after the suggestions, also by Keeney (1994: 35), may be asked to aid the decision-maker during the process.

1. *Develop a wish list.* What do you want? What do you value? What should you want?
2. *Identify alternatives.* What is a perfect alternative, a terrible alternative, some reasonable alternative?
3. *Consider problems and shortcomings.* What needs fixing?
4. *Predict consequences.* What has occurred that was good or bad? What might occur that you care about?
5. *Identify goals, constraints, and guidelines.* What are your aspirations? What limitations are placed on you?
6. *Consider different perspectives.* What would your competitor or constituency be concerned about? At some time in the future, what would concern you?
7. *Determine strategic objectives.* What are your ultimate objectives? What are your values that are absolutely fundamental?
8. *Determine generic objectives.* What objectives do you have for your customers, your employees, your shareholders, yourself? What

environmental, social, economic, or health and safety objectives are important?

Another method that may be used to aid the decision-maker in generating objectives is the "gold standard" (Kloeber, 2000). Many decision-makers often have limited time to spend on one particular problem. Developing the decision-maker's objectives hierarchy can be a lengthy process depending on the complexity of the problem and the decision-maker's knowledge of the problem. With the gold standard, the analyst deductively develops a list or hierarchy of potential objectives based upon documents containing the decision-maker's strategic vision and objectives or from other documents such as doctrine (Kloeber, 2000). Essentially, a "strawman" is developed to serve as a starting point when the decision-maker and analyst meet to develop the objectives hierarchy.

2.6.2.2 Structuring Objectives. Once the decision-maker's objectives regarding the decision context are determined, these objectives can be arranged in a hierarchical or treelike structure to provide an illustration of the factors the decision-maker considers important in evaluating the problem. The treelike structure also shows how these objectives relate to one another with regard to the decision context. The upper tiers in a hierarchy represent more general objectives while the lower tiers describe important elements of the more general objective levels. Moving down the hierarchy from an upper-tier objective answers the question, "What do you mean by that?" Moving up the hierarchy from a lower-tier answers the question, "Of what more general objective is this an aspect?" (Clemen, 1996: 47).

Figure 7 shows a hypothetical objectives hierarchy for an operations research professor seeking a new job after retiring from the military (Kloeber, 2000). In this decision situation, the strategic objective is selecting the job opportunity that will provide the most job satisfaction. The three lower-tier objectives of *Compensation*, *Family*, and *Work Environment*, explain what the decision-maker means by "job satisfaction."

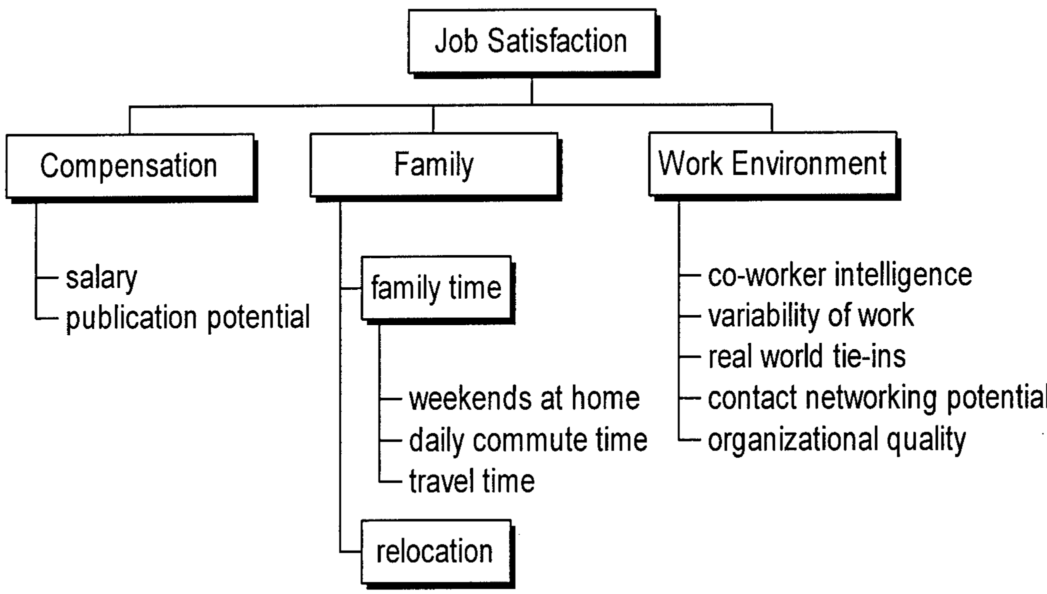


Figure 7. A Hypothetical Objectives Hierarchy (Kloeber, 2000)

2.6.2.3 Desirable Properties of an Objectives Hierarchy. Desirable properties for an objectives hierarchy include completeness, nonredundancy, decomposability, operability, and small size (Kirkwood, 1997: 16). First, for an objectives hierarchy to be complete, the objectives at each tier in the hierarchy, taken together as a group, must adequately cover all concerns necessary to evaluate the strategic (overall) objective of the decision (Kirkwood 1997: 16). Second, nonredundancy implies that no two objectives in the same tier of the hierarchy should

overlap. The two properties of completeness and nonredundancy are sometimes expressed by saying that the objectives in each tier of an objectives hierarchy must be "mutually exclusive and collectively exhaustive" (Kirkwood, 1997: 17). Third, decomposability means that there must be a way to measure each objective in order to determine the overall preferability of alternatives. Fourth, operability refers to making the objectives hierarchy understandable for the people who must use it. If the decision-maker does not understand the hierarchy, he or she most likely will not use it. Finally, a small objectives hierarchy is desired because it is easier to communicate to interested parties. Additionally, it requires fewer resources during the modeling process when information regarding the performance of alternatives with respect to the various objectives needs to be collected (Kirkwood: 1997: 18).

2.6.3 Step 3 - Develop Evaluation Measures. Once the objectives hierarchy is created, evaluation measures (metrics) are developed for each of the objectives in the last tier of each branch in the hierarchy. For example, referring back to the hypothetical objectives hierarchy found in Figure 7, *Compensation* is the last tier objective for the leftmost branch on this hierarchy. *Salary* and *Publication Potential* are evaluation measures for *Compensation*. The decision analysis team must select the unit of each evaluation measure, the scale type, the measure type, and the lower and upper bounds of the scale.

Evaluation measures are classified as having either natural or constructed measures, and also either direct or proxy scales (Kirkwood, 1997: 24). A natural scale is one that is in general use with a common interpretation by everyone. As an example, dollars is a natural scale for the evaluation measure *Salary*. A constructed scale is one

that is developed for a particular decision problem usually because a natural scale does not exist or is not appropriate. "A direct scale directly measures the degree of attainment of an objective, while a proxy scale reflects the degree of attainment of its associated objective, but does not directly measure this" (Kirkwood, 1997: 24). Kirkwood (1997: 24) uses profits in dollars and gross national product as examples of a direct and proxy scale, respectively. Continuing with the hypothetical job search example, for the evaluation measure *Salary*, the units for this measure are dollars which is a natural scale and a direct measure. A reasonable range for this measure determined by the professor may be from $50,000 to $140,000. It is important to define the range of the evaluation measures in this step because the weights that will be assigned to each measure in a later step in the decision support process depend on the variation (x-axis) of the evaluation measures (Parnell and Kloeber, 2000: 7).

2.6.4 Step 4 - Create Value Functions. Since the evaluation measures developed in the previous step are usually in different units and measured on different scales, it is impossible to sum the individual measurements to obtain a total score. Once again, referring back to the hypothetical objectives hierarchy in Figure 7, how does one combine *Salary* (measured with dollars) and *Publication Potential* (measured with publications every 5 years) into common units? To solve this problem, value functions are developed to transform the units of each evaluation measure into "value units" on a scale of 0 to 1 (Kirkwood, 1997: 61). Imagine an evaluation measure that has its worst possible score at x and its best possible score at y and the values associated with these extremes are 0 and 1, respectively. To determine intermediate value units for alternatives that score between the extremes, the literature suggests several methods. Perhaps the

easiest method is direct assessment, where the decision-maker uses his or her judgment and experience to provide value units associated with each alternative's evaluation measure.

A value function developed from this process is single-dimensional and is either *monotonically increasing* or *monotonically decreasing*. Figure 8 illustrates an evaluation measure in which the decision-maker's value towards the objective is *monotonically increasing*. Thus, as an evaluation measure score increases from x to y, the value to the decision-maker increases from 0 to 1. The three value functions in the figure show different rates at which increased evaluation measure scores translate into increased value. Value function "1" shows a decision-maker who believes the value associated with the evaluation measure has a marginally decreasing rates of return. On the other hand, value function "3" shows a decision-maker who believes the value associated with the evaluation measure has marginally increasing rates of return. Value function "2" show a decision-maker who believes the rate of return is constant throughout the evaluation measure.

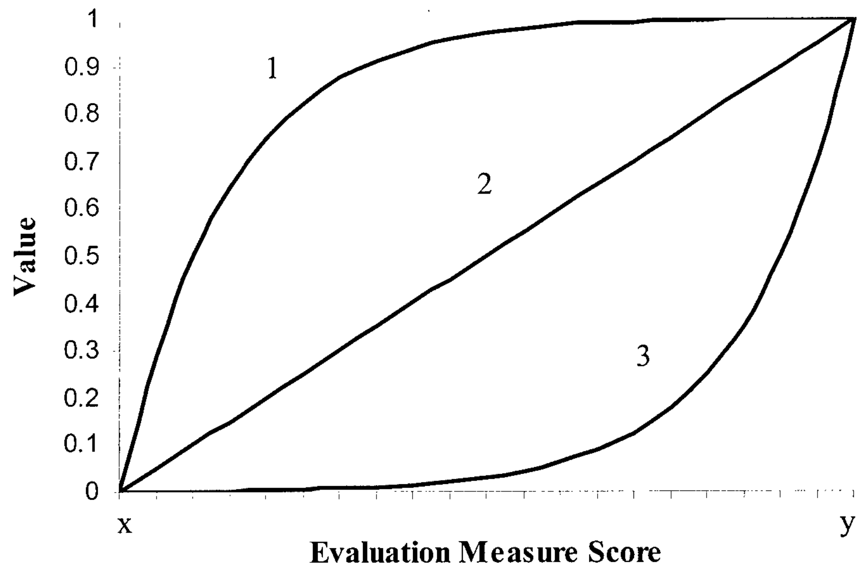


Figure 8. Examples of Monotonically Increasing Value Functions (Kirkwood, 1997)

Figure 9 illustrates an evaluation measure in which the decision-maker's value towards the objective is *monotonically decreasing*. Thus, as an evaluation measure score increases from x to y, the value to the decision-maker decreases from 1 to 0. The three value functions in the figure show different rates at which increased evaluation measure scores translate into decreased value. Value function "1" shows a decision-maker who believes the value associated with the evaluation measure has a marginally decreasing rates of return. On the other hand, value function "3" shows a decision-maker who believes the value associated with the evaluation measure has marginally increasing rates of return. Finally, value function "2" show a decision-maker who believes the rate of return is constant throughout the evaluation measure.

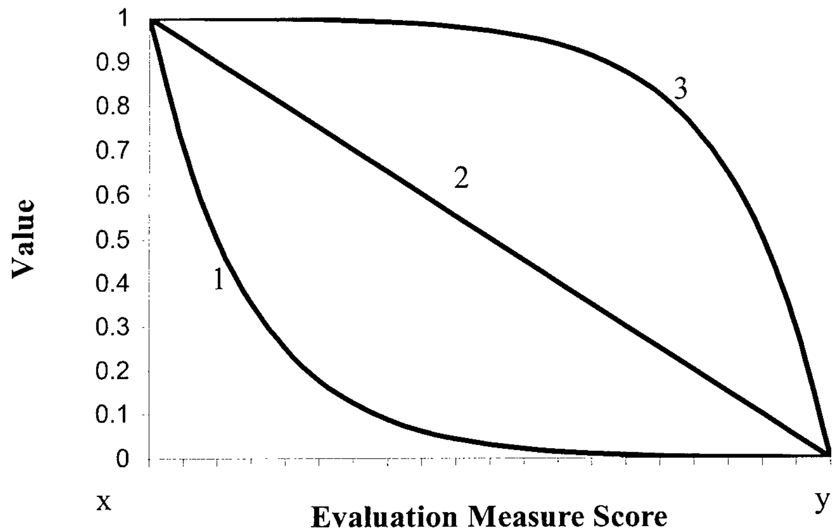


Figure 9. Examples of Monotonically Decreasing Value Functions (Kirkwood, 1997)

Figure 10 presents a hypothetical value function for the evaluation measure *Salary* from the job search example. This is a monotonically increasing single-dimensional value function.

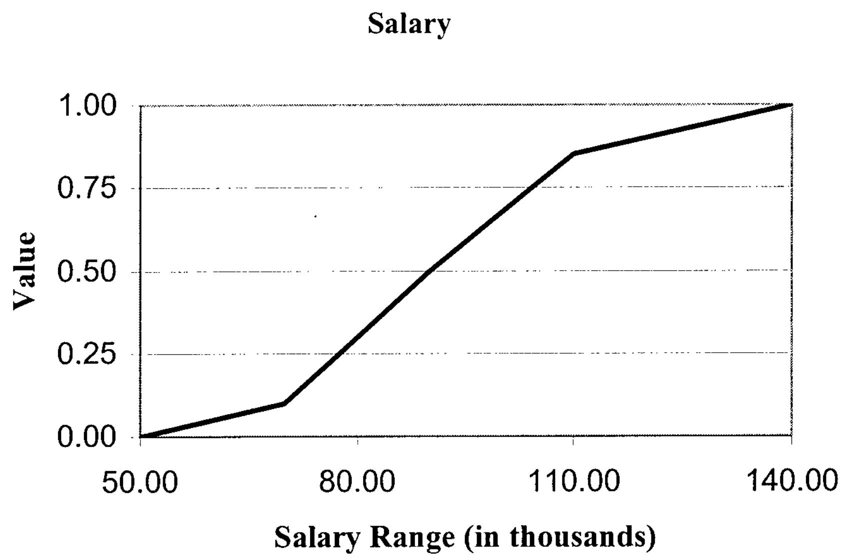


Figure 10. Hypothetical Value Function (Kloeber, 2000)

2.6.5 Step 5 - Objectives Hierarchy Weights. The objectives hierarchy is composed of the multiple objectives the decision-maker has in making a decision. However, each of these objectives is not necessarily equally important to the decision-maker. To account for this varying degree of importance, weights must be assigned to the objectives. One method of assigning weights is the direct weighting technique, which is a direct assessment of the importance of one objective over another without considering how much that objective actually contributes to the total score of the alternatives (von Winterfeldt and Edwards, 1986:274). This weighting technique creates

two different types of weights: local and global. A local weight refers to how much weight a set of sub-objectives contributes to the objective directly above it. A global weight refers to how much weight each of the lowest tier objectives contributes to the overall objective at the very top of the hierarchy in relation to each other.

The hypothetical objectives hierarchy in Figure 7 used earlier in this section will be used to explain how local and global weights are obtained. First, local weights are found for the lowest tier of objectives on each branch of the objectives hierarchy with respect to the next tier of objectives above it. For example, *Family Time* and *Relocation* are the lowest tier objectives on the middle branch of the hierarchy. The next objective up the hierarchy from these two objectives is *Family.* To obtain the local weights for *Family Time* and *Relocation*, the decision-maker is asked which of these two objectives is least important. In this example, assume the decision-maker indicates *Relocation* and a variable of x is assigned to this objective. The decision-maker is then asked how much more important the objective *Family Time* is in relation to the objective *Relocation*. Assume the decision-maker indicates it is twice as important and a variable of $2x$ is assigned to it. The sum of the local weights must equal one, so $x + 2x = 1$. This equation results in a value of 1/3 for x. Therefore, *Relocation* has a local weight of 1/3 while *Family Time* has a local weight of 2/3 with respect to the objective *Family.* This process is repeated for all other lowest tier objectives with respect to the next tier of objectives above them. In this particular example, the middle branch is the only branch with a third tier of objectives. After completing a tier, the next step is to move up the hierarchy to the next tier of objectives. As one can see from Figure 7, *Compensation*, *Family*, and *Work Environment* are on the next tier. The weighting process just described is repeated for

these objectives with respect to the objective *Job Satisfaction*. Again, the weights must sum to one. This process is repeated until the top-tier objective is reached. Once all the local weights are obtained in this manner, it is a matter of simple algebra to find the global weights for each of the lowest tier objectives with respect to the overall objective at the very top of the hierarchy.

While determining the weights, the analysts should make the decision-maker well aware of the range scale of each objective so that the decision-maker knows exactly what is being compared. Weighting the objectives without taking range into consideration is dangerous since importance will increase or decrease tremendously depending on the range (Kloeber, 2000).

2.6.6 Step 6 - Alternative Generation. In this step, the decision-maker determines which alternatives or strategies should be considered. Howard (1988: 684) suggests a strategy generation table as one way of creating alternatives. A typical strategy generation table appears in Figure 11. In this illustration, an Air Force commander must develop a strategy to ensure air superiority. For each decision strategy theme, the commander must decide which aircraft to use, the number of aircraft to use, and which target to attack. The table lists alternatives for each of these decisions. The strategy generation table forces creative thought about different types of alternatives and may prompt the decision-maker to consider combinations of options that were not considered before (Kloeber, 2000).

Air Superiority Mission Profile

Strategy Theme	Type of Aircraft	Number of Aircraft	Target to Attack
Dogfight	B-1B	15	Hardened Aircraft Shelter
Disable Aircraft	F-15E	10	Airfield
Destroy on the Ground	F-16	5	Aircraft in the Air

Figure 11. Example Strategy Generation Table

2.6.7 Step 7 - Alternative Scoring. Once the alternatives to be evaluated are known, data needs to be collected in order to score each alternative in relation to the evaluation measures. Depending on the number of evaluation measures and the availability of the data required to score an alternative, this can be a lengthy process.

2.6.8 Step 8 - Deterministic Analysis. The data collected from steps 4 (value functions), 5 (weights), and 7 (alternative scores) are used in a spreadsheet decision model to form an overall value function. The purpose of the overall value function is to rank order model results in a manner consistent with the decision-maker's preferences for those outcomes (Clemen, 1996: 552).

There are several different types of overall value functions that rank alternatives based on multiple objectives (Kirkwood, 1997: Ch 9). The more commonly used ones are the multiplicative value function and the additive value function. The simplicity of the additive value function is particularly appealing for use in prescriptive decision

analysis because the underlying basis is easily understood and allows extensive sensitivity analysis (Stewart, 1995: 252). For this reason, the additive value function will be used in this decision support model.

In order to use the additive value function, single-dimensional value functions $v_n(x)$ must be specified for each evaluation measure n and weights (λ_n) must be specified for each single-dimensional value function (Kirkwood, 1997). The additive value function combines multiple single-dimensional value functions $v_1(x_1), \ldots, v_n(x_n)$ with evaluation measure scores x_1 through x_n for each alternative into a single measure of the overall value of each alternative. The additive value function assumes each single-dimensional value function contains a value of 0 for the worst evaluation measure score and 1 for the best evaluation method score. Under these assumptions, the additive value function is simply a weighted average of the different value functions expressed as

$$v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) \tag{2.1}$$

where the weights ($\lambda_1, \ldots, \lambda_n$) are positive and sum to one (Kirkwood, 1997: 230).

It should be noted that the additive value function does not contain any interaction terms, implying that the decision-maker's preferences associated with any one objective are independent of the evaluation measure scores associated with all other objectives. This condition is called preferential independence. For example, if the professor from the job satisfaction example prefers high *Compensation* over low *Compensation*, regardless of the level of *Work Environment*, then *Compensation* is preferentially independent of the *Work Environment* objective. If preferential independence holds for all possible combinations of objectives, the objectives are considered mutually preferential

independent and the additive value function properly models the decision-maker's preferences under certainty (Kirkwood, 1997: 239).

2.6.9 Step 9 - Sensitivity Analysis. Analyzing the sensitivity of the alternative rankings to changes in weight values often provides the decision-maker with valuable insight. To accomplish this analysis, the weight of each value is systematically altered and the subsequent impact on the final scores and rankings are tracked. As an individual weight is changed, the other weights are adjusted to ensure the sum remains one. The proportionality of the other weights to each other is maintained as the weight being assessed is adjusted.

2.6.10 Step 10 – Recommendations Presentation. Once the deterministic and sensitivity analysis are complete, recommendations are presented to the decision-maker. The format of the presentation depends on the insights gained during the analysis and the questions posed by the decision-maker.

Chapter 3. Methodology

Determining which combination of suitable waste management techniques, technologies, and management programs is best suited to meet Eareckson Air Station's (AS) overall municipal solid waste (MSW) goals is very complex. There are several ways to manage Earckson's MSW and each must be evaluated against multiple criteria: How much are operations and maintenance costs? What are the potential environmental impacts? Are Air Force waste diversion goals being met? These are just a few of the potential criteria a decision-maker may use to evaluate this problem. Given the number of MSW management alternatives and the multiple objectives they must be evaluated against, this problem is well suited for multiple-objective decision analysis techniques.

Value-focused thinking, which utilizes multiattribute preference theory, was selected as the best method for creating a deterministic decision analysis model to select a MSW management strategy for Eareckson AS. A value-focused thinking approach captures the decision-maker's preferences towards each of his or her objectives and provides a method for measuring how well alternatives meet these objectives. Strategies are then ranked based on their value to the decision-maker.

The framework for this study, discussed in Chapter 2, is illustrated in Figure 12. The decision-maker for this problem is the 611th Civil Engineer Squadron (611 CES) Environmental Flight commander, who is responsible for all environmental programs at Eareckson AS to include MSW management. A series of elicitation interviews with the decision-maker and his representatives were used to collect information for the decision support model. Appendix A lists the names of the key personnel involved.

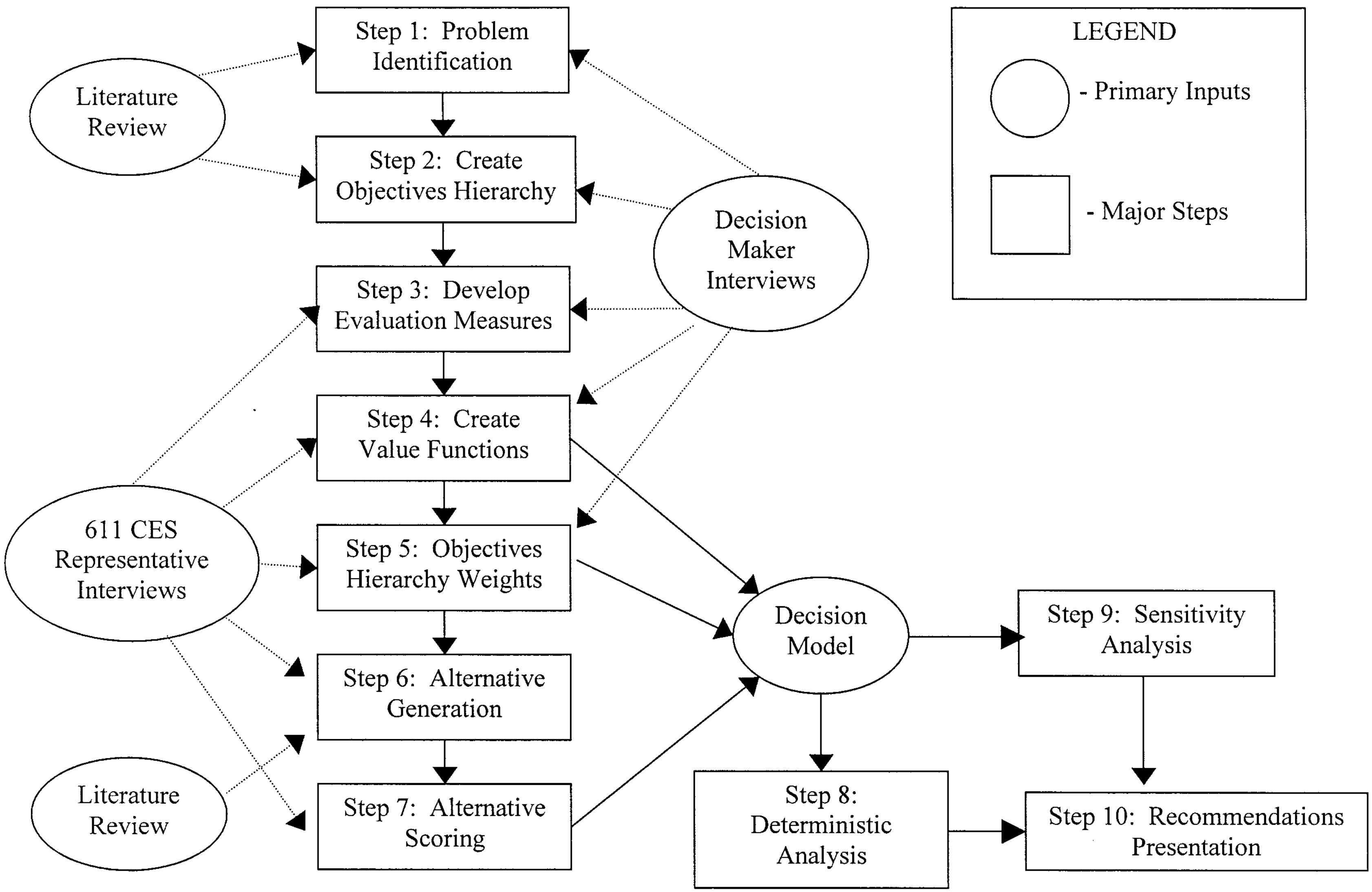


Figure 12. Decision Support Model Development Framework

This chapter begins by identifying the problem, explaining the decision-maker's objectives, and describing how evaluation measures quantifying the objectives were gathered. Next, this chapter explains how weights and value functions for the decision-maker's objectives were determined. Finally, this chapter identifies the MSW strategies generated by the decision-maker for evaluation by the model. The data collection and analysis of model data will be described in Chapter 4.

3.1 Step 1 – Problem Identification

The first step in any decision problem is identifying the specific problem the decision-maker (DM) wishes to solve. The result of this step should be a well-defined statement of the problem. An interview with the DM for MSW issues at Eareckson AS clearly identified the overall management of MSW as a problem. The station's current MSW disposal system, which consists solely of a landfill, is out of environmental compliance with state of Alaska and federal regulations. In addition, the station has not been working towards Air Force-mandated waste diversion goals. Eareckson AS needs a new solid waste management system and strategy to address these issues. There are a few well known methods for managing MSW, but identifying the best method or combination of methods is a difficult task. Clearly stated, the problem is: *Which combination of suitable waste management techniques, technologies, and management programs is best suited to meet Eareckson Air Station's overall MSW goals and is consistent with the decision-maker's objectives and concerns regarding MSW management?*

3.2 Step 2 – Objectives Hierarchy

In this step, the criteria or objectives that are important to the DM in making this decision are developed and used to construct a hierarchy of objectives. This is one of the most important steps in the process since the objectives hierarchy is referenced throughout the modeling process. Various methods for determining and structuring the decision-maker's objectives were discussed in Chapter 2. For this research effort, some of the objectives elicitation techniques suggested by Keeney (1994: 35) were employed during an interview with the decision-maker. Specifically, questions asked by the author of this thesis to aid the decision-maker included: What are your ultimate objectives? What are your values that are absolutely fundamental? What is a perfect alternative, a terrible alternative, a reasonable alternative? What environmental, social, economic, or health and safety objectives are important? Figure 13 presents the resulting objectives hierarchy established during this interview process. Thus, for this research problem, Figure 13 presents the decision-maker's objectives against which each alternative will be evaluated.

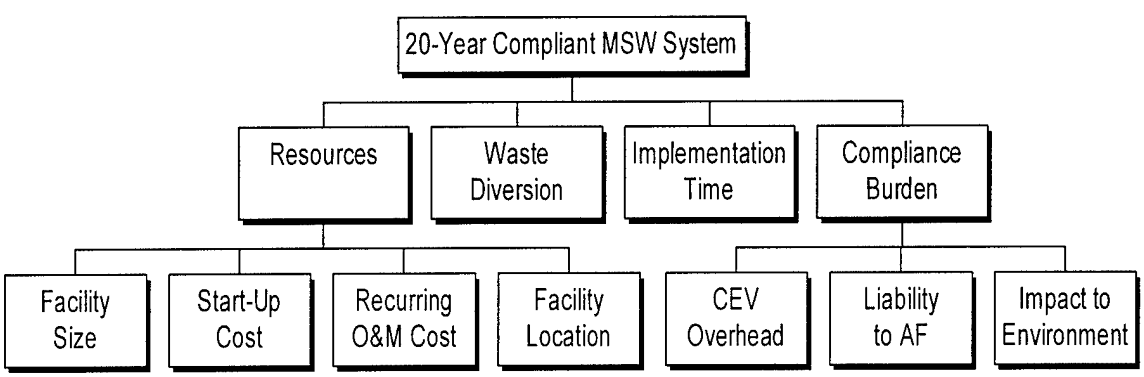


Figure 13. Eareckson AS Objectives Hierarchy

The DM feels these objectives are the only ones applicable to this decision situation. Therefore, the hierarchy is complete. In addition, the hierarchy is nonredundant since no two objectives on the same tier of the hierarchy overlap. Thus, the objectives are mutually exclusive and collectively exhaustive. A detailed discussion of each objective follows beginning with the overall objective, *20-Year Compliant MSW System*, then proceeding from the leftmost branch towards the rightmost branch. The second-tier objectives (*Resources*, *Waste Diversion*, *Implementation Time*, and *Compliance Burden*) are general objectives. The third-tier objectives beneath some of the general objectives provide more detail about what the DM meant by the general objective.

3.2.1 20-Year Compliant MSW System. The decision-maker's overall objective on the first-tier of the hierarchy is a *20-year Compliant MSW System*. This overall objective establishes both a screening criteria and a study period. Only alternatives that will be compliant with current environmental regulations will be considered. In addition, a 20-year study period was chosen because this is the typical landfill life expectancy design standard used by the 611 CES; a 20-year timeframe also provides a common study period to compare alternatives with unequal service lives.

3.2.1.1 Resources. The first of four second-tier objectives on the objectives hierarchy is *Resources*. Land for development and funds are limited resources at Eareckson AS; therefore the DM wants to minimize costs and land usage. The third-tier objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost*, and *Facility Location* provide more specific information about the general objective *Resources*. Since the DM valued *Start-Up Cost* (a one-time project cost) and *Recurring O&M Cost* (an annual cost

for operations and maintenance (O&M) of the MSW system) differently, cost is broken down into two separate objectives.

3.2.1.1.1 Facility Size. Eareckson AS is located on a small island and the area available for a new landfill (or any other new facilities) is limited by several factors: terrain and regulatory requirements, an active airfield, most of the island is classified as a wetland, and several contaminated sites. Because of Eareckson's limited land resources, the DM desires the smallest landfill facility to meet Eareckson's MSW disposal needs over the next 20 years.

3.2.1.1.2 Start-Up Cost. Like most military installations, Eareckson AS has multiple project requirements competing for the same limited project funds. The project implementing a new MSW management system at Eareckson is not only in competition against other projects for Eareckson AS, but is competing for funds against project requirements at 23 other remote facilities within the 611th Air Support Group.

3.2.1.1.3 Recurring O&M Cost. MSW management at Eareckson AS is part of the Eareckson AS Base Operations Support (BOS) contract. Funding for these types of contracts comes from a different funds source than project funds. This helps explain why the DM values start-up and recurring O&M costs differently instead of combining all costs into one net present-worth cost objective. If the estimated O&M cost for a new MSW management system exceeds the current system's O&M cost, the BOS contractor is entitled to an increase in the contract cost. On the other hand, if the cost estimate for the new system were lower than the current system's O&M cost, the government would be entitled to a decrease in contract cost.

3.2.1.1.4 Facility Location. The Eareckson landfill, located on the southeast point of Shemya Island, has been operational since 1944 (Eareckson AS, 1994). A landfill life expectancy survey conducted in 1994 indicated that the current landfill location still had over 20 years of life expectancy at current estimated disposal rates (Semmler, 1994). The DM values utilization of this remaining resource and desires to maximize the landfill's life expectancy. As far as locations for any potential recycling, composting, or incineration facilities, the DM is not concerned with these because there are several inactive hangars, warehouses, and paved areas that may be used to accommodate these types of operations.

3.2.1.2 Waste Diversion. The second of four second-tier objectives on the objectives hierarchy is *Waste Diversion*. Air Force Instruction 32-7080, "Pollution Prevention Program," states that pollution prevention is one of the Air Force's main objectives (Department of the Air Force, 1994: 1). In addition, a Deputy Undersecretary of Defense (Environmental Security) policy memorandum has established MSW diversion goals for the Air Force (Goodman, 1998), which the DM desires to meet.

3.2.1.3 Implementation Time. The third of four second-tier objectives on the objectives hierarchy is *Implementation Time*. The Eareckson landfill is currently out of environmental compliance with federal and state solid waste regulations. This exposes Eareckson AS and the Air Force to potential regulatory action by the Alaska Department of Environmental Conservation (ADEC). While no deadline has been set by ADEC as to when Eareckson needs to have a compliant MSW system in place, implementation time is still a very important value to the DM.

3.2.1.4 Compliance Burden. The final second-tier objective on the objectives hierarchy is *Compliance Burden*. The third-tier objectives *CEV Overhead*, *Liability to AF*, and *Impact to Environment* provide more specific information about the general objective *Compliance Burden*.

3.2.1.4.1 CEV Overhead. As stated earlier, the BOS contactor at Eareckson AS is responsible for operations and maintenance of the MSW management system at Eareckson. However, engineering support, design, planning, regulatory interaction, and management oversight of the BOS contractor's environmental operations are the responsibility of the 611 CES Environmental Flight (CEV). The DM is concerned about the additional workload for CEV personnel as a result of implementing any of the MSW management alternatives.

3.2.1.4.2 Liability to Air Force. Almost all facets of MSW, from waste generation to disposal, are regulated and require permits. Determining which regulations apply and which permits are required depends on the MSW management elements and techniques that are part of the system. For example, regulations for incinerator air emissions do not currently apply to Eareckson AS since there is not an incinerator. However, if an incinerator facility were added to the MSW system, Eareckson would be responsible for complying with these regulations and the conditions of the air permit. The DM is concerned about the potential liability each MSW alternative may pose to Eareckson and the Air Force. More regulations and permit requirements translate into a greater potential liability for fines and notice-of-violations (NOVs) by some regulatory body.

3.2.1.4.3 Impact to Environment. Most MSW management techniques have the potential to impact the environment. Both landfills and incinerators can impact water and air quality. Leachate from composting operations may also impact water quality and cause an odor nuisance. In addition, composting and landfill facilities can cause an animal nuisance. The potential environmental impact of each MSW strategy is quite important to the DM.

3.3 Step 3 – Evaluation Measures

Having developed the Eareckson AS objectives hierarchy, the next step involves developing evaluation measures for each of the objectives in the last-tier of each branch in the objectives hierarchy in order to assess how well an alternative meets the objectives. Table 9 provides a summary of the evaluation measures created by the DM and the CEV staff for each of the last-tier objectives in the Eareckson AS objectives hierarchy. An explanation of each evaluation measure follows the table, with the range of each measure being discussed in the value functions section later in this chapter. Data collected for each evaluation measure will be presented in Chapter 4.

Table 9. Summary of Measures to Evaluate Alternatives

Objective	Measure Unit	Scale Type	Measure Type	Lower Bound	Upper Bound
Facility Size	Square Feet	Natural[a] Direct[b]	Quantity	52,000 SF	104,000 SF
Start-Up Cost	Dollars	Natural Direct	Quantity	\$1M	\$5M
Recurring O&M Cost	Dollars	Natural Direct	Quantity	\$10K	\$50K
Facility Location	Miles from Current Landfill	Constructed[c] Direct	Quantity	0 Miles	3 Miles
Waste Diversion	% Solid Waste Diverted from Disposal	Natural Direct	Quantity	0% Diverted	50% Diverted
Implementation Time	Time in Years	Natural Direct	Quantity	1 yrs	6 yrs
CEV Overhead	Manhours Spent Working MSW Related Issues	Constructed Proxy[d]	Quantity	40 hrs	160 hrs
Liability to AF	Number of Permits Required for Operations	Constructed Proxy	Quantity	2 Permits	5 Permits
Impact to Environment	ISWM Hierarchy	Constructed Proxy	Category	Landfill & Incineration	Landfill & Recycling

[a] A natural scale is one that is in general use with a common interpretation by everyone.

[b] A direct scale directly measures the degree of attainment of an objective.

[c] A constructed scale is one that is developed for a particular decision problem usually because a natural scale does not exist or is not appropriate.

[d] A proxy scale reflects the degree of attainment of its associated objective, but does not directly measure it.

3.3.1 Evaluation Measure for Facility Size. The estimated size of the new landfill in square feet is the natural, direct measurement used to evaluate the facility size. Since the area available for a new landfill at Eareckson Air Station is extremely limited, the smaller the landfill footprint, the more area available for future activities. The size of the new landfill was initially estimated assuming all waste generated is landfilled. Additional assumptions were made regarding waste characterization, population size, waste generation rates, landfill cover to waste ratios, and waste compaction ratios. Theoretically, this is the largest (upper bound) footprint expected for a 20-year landfill. The smaller facility size (lower bound) was estimated by incorporating the different solid waste management techniques and technologies available to manage the waste stream.

3.3.2 Evaluation Measure for Start-Up Cost. Cost in dollars is the natural, direct measurement scale used to evaluate this objective. Start-up cost, more commonly known as project cost, is the one-time cost necessary to implement a solid waste management system alternative.

3.3.3 Evaluation Measure for Recurring O&M Cost. Once again, cost in dollars is the natural, direct measurement scale used to evaluate this objective. However, recurring O&M cost is the annual cost of operating and maintaining a particular solid waste management system alternative.

3.3.4 Evaluation Measure for Facility Location. The measurement used to evaluate this objective is the constructed, direct scale of distance in miles between the new and current landfill locations. The DM prefers to retain the current landfill location, or locate a new landfill as close to the old one as possible, since there is still available area at the site and the borrow source for landfill cover is adjacent to the site.

3.3.5 Evaluation Measure for Waste Diversion. To measure *Waste Diversion*, the percentage of solid waste diverted from landfill and incinerator disposal through recycling and composting will be used. This natural, direct measure will require current waste characterization data.

3.3.6 Evaluation Measure for Implementation Time. Time is a natural, direct scale for the objective *Implementation Time*. The various solid waste management technologies require different implementation times due to design, manufacturing, transportation, and construction constraints (for example, the construction season at Eareckson is May through September). Implementation time is measured by estimating the time it will take in years to implement a particular alternative considering the above constraints.

3.3.7 Evaluation Measure for CEV Overhead. The amount of CEV overhead required for a particular solid waste management alternative is measured by estimating the amount of contractor oversight and regulator interaction in manhours per year required by the environmental flight (this is a constructed, proxy scale). While the BOS contractor is responsible for interfacing with the regulators as the operator of the solid waste system, the 611 CES oversees the actions of the BOS contractor and interfaces with the regulators as the owner of the solid waste system.

3.3.8 Evaluation Measure for Liability to Air Force. The number of permits required for a MSW alternative is the constructed, proxy measure for this objective. The greater the number of permits required by a MSW system is related to the amount of liability the Air Force assumes since each permit has compliance conditions that must be met.

3.3.9 Evaluation Measure for Impact to Environment. Each solid waste management technology possesses potential risks to the environment. Hazardous wastes improperly disposed in the landfill may leach into the underlying aquifer, emissions from an incinerator may exceed air quality limits, and a composting facility may create a bird and animal hazard. These are just some of the impacts a solid waste system may have on the environment. Because of the difficulty in determining the risk a particular solid waste management alternative actually poses, the environmental impact of a particular solid waste system is measured using a constructed, proxy scale based upon the ISWM hierarchy. As discussed in Chapter 2, the ISWM hierarchy is the preferred order of the four different MSW management techniques (recycling, composting, incineration, and landfilling). Figure 14 ranks the different combinations of MSW management techniques from the hierarchy based upon the DM's perception of the environmental impact (an "x" indicates which techniques are included in a combination). Note that landfilling is part of all combinations since there has to be a landfill. An explanation of why the DM ranked these combinations as shown will be provided in the next section.

Rank	Landfill	Incineration	Composting	Recycling
1 (Best)	x	-	-	x
2	x	-	x	x
3	x	-	x	-
4	x	x	-	x
5	x	x	x	x
6	x	x	x	-
7	x	-	-	-
8 (Worst)	x	x	-	-

Figure 14. Impact to Environment Evaluation Measure

3.4 Step 4 – Value Functions

The evaluation measures developed in step 3 usually consist of different measurement units and different scales. Therefore, it is algebraically incorrect to sum the individual value measures for an alternative into a total score. To solve this problem, value functions are developed to convert the units of each evaluation measure into "value units," which range from 0 to 1. Once this conversion has occurred, the value units for each individual value measure may be summed into a total score for the alternative.

The following value functions were developed with the DM and CEV staff using a direct assessment technique. First, the best and worst possible scores (the extremes) for each evaluation measure were determined to establish the 0 and 1 points on the value scale. These extremes are based either on judgment and experience or by the known data set. Several intermediate points were selected for each measure to represent various alternatives and the DM was asked how much value should be assigned to a corresponding alternative at that point.

3.4.1 Landfill Size Value Function. The graph in Figure 15 converts each alternative's landfill footprint from square feet into value units. The decision team (DM and CEV staff) estimated that a new 20-year landfill (no recycling, composting, or incineration) would require 104,000 square feet of land based upon a landfill site selection report by Jacobs (2000). This was considered a worst-case scenario and assigned a value of 0. The team selected a landfill size of 52,000 square feet (half the 20-year landfill size) as a best-case scenario and assigned it a value of 1. It should be noted that size reductions greater than 50 percent were valued the same by the team. As one can see from the graph in Figure 15, the function represents an s-shaped curve. The DM

is mostly indifferent about landfill square footage within 20 percent of either respective extreme; thus there is only a slight difference in the corresponding values. Between 62,400 and 93,600 square feet, the DM believes the rate of decrease in value is constant.

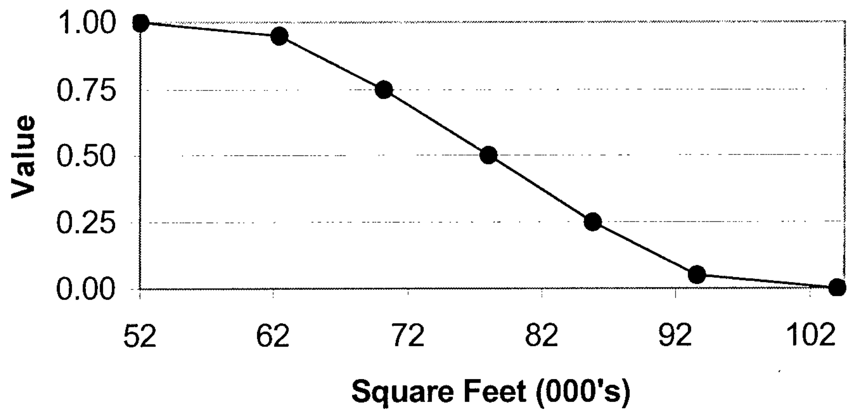


Figure 15. Facility Size Value Function

3.4.2 Value Function for Start-Up Cost. The graph in Figure 16 converts each alternative's start-up cost in dollars into value units. As expected, the value decreases as the start-up cost decreases because the DM wants to minimize project costs. The minimum cost of the last five new landfill projects for the 611 CES was one million dollars ($1M). Since it is doubtful that the Eareckson landfill would be any less expensive, the decision team selected $1M as the best-case scenario and assigned it a value of 1. The team estimated it would cost $5M to construct a new landfill, incinerator, composting, and recycling facilities. Therefore, $5M was selected as the worst-case scenario and assigned a value of 0. While the DM feels that a project cost between $1M and $2M is reasonable and funds are obtainable in this range, the DM's value of start-up costs greater than $2M decrease more dramatically. The value score drops considerably from $2M to $3M because a project cost in this range would cause several less pressing project requirements to go unfunded. Finally, any project costing more than $3M is not valued very highly because it could potentially consume the entire environmental compliance project budget for the year.

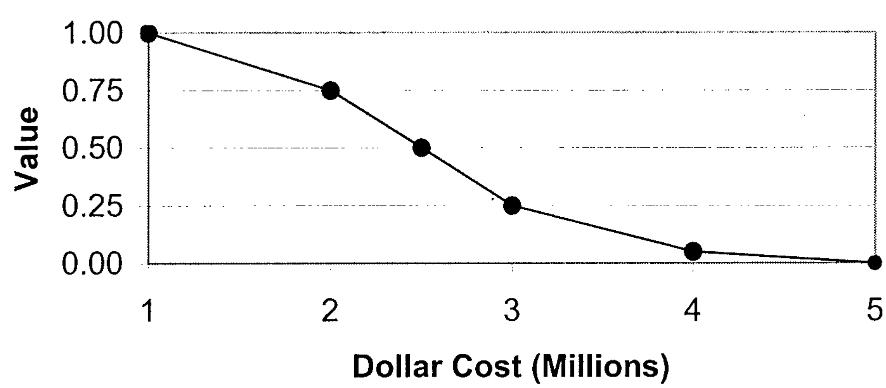


Figure 16. Start-Up Cost Value Function

3.4.3 Recurring O&M Cost Value Function. The graph in Figure 17 converts each alternative's recurring O&M cost in dollars into value units. As expected, the value decreases as the cost increases. The decision team selected $10,000 ($10K) as the best-case scenario and assigned it a value of 1 because it is close to the O&M cost for the current MSW system. The team selected $50K as the worst-case scenario because O&M costs greater than this amount are not desired. The linear relationship indicated by the graph indicates that the DM believes the rate of decrease in value is constant throughout the evaluation measure range.

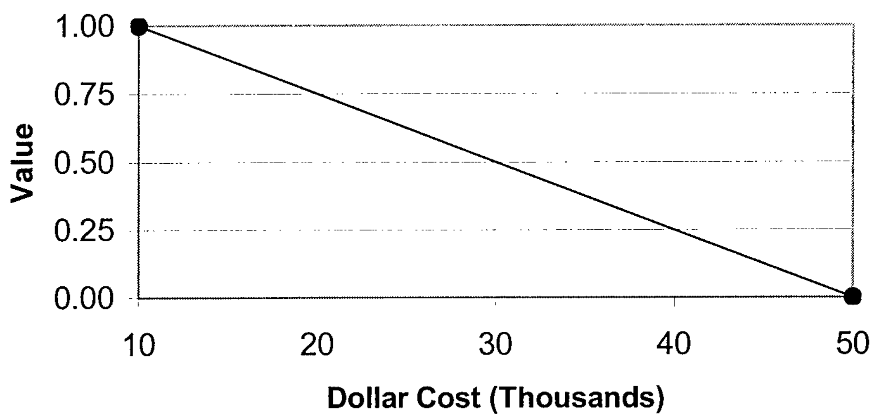


Figure 17. Recurring O&M Cost Value Function

3.4.4 Landfill Location Value Function. The graph in Figure 18 converts each alternative's landfill location, measured by the distance from the current landfill location, into value units. The DM selected zero miles as the best-case scenario and assigned it a value of 1 because being able to utilize the remaining space at the current landfill location is desired the most. The DM selected 3 miles as the worst-case scenario because this is the furthest distance away from the current landfill that a new landfill could be located due to size of the island. The DM places high value on distances up to 0.5 miles because of the proximity to the borrow source. At values greater than 0.5 miles, the value drops considerably.

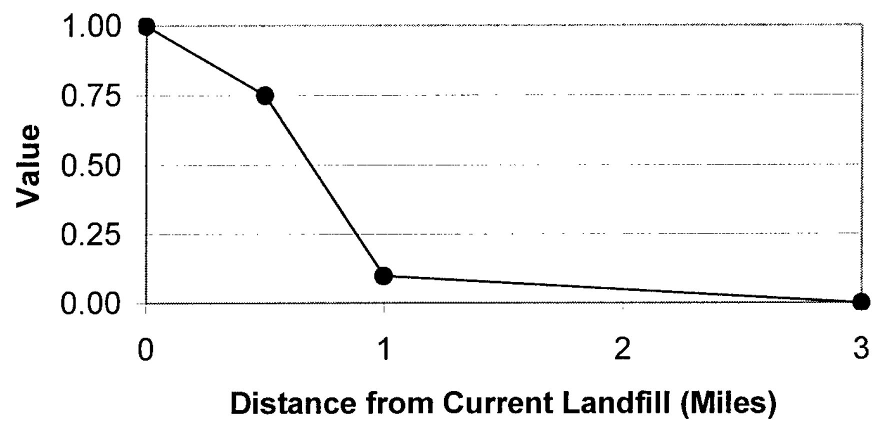


Figure 18. Landfill Location Value Function

3.4.5 Waste Diversion Value Function. The graph in Figure 19 converts each alternative's percentage of solid waste diversion from landfill and incinerator disposal facilities into value units. The team selected 0 percent diversion as the worst-case scenario, which is the current case at Eareckson, and 50 percent diversion as the best-case scenario; these amounts were assigned values of 0 and 1 respectively. Value increases quickly from 0 to 20 percent diversion because the DM feels that anything in this range is a reasonable diversion rate considering Eareckson's location; a 20 percent diversion rate would be considered very successful. The waste diversion value function varies linearly with diversion rates ranging from 20 to 50 percent.

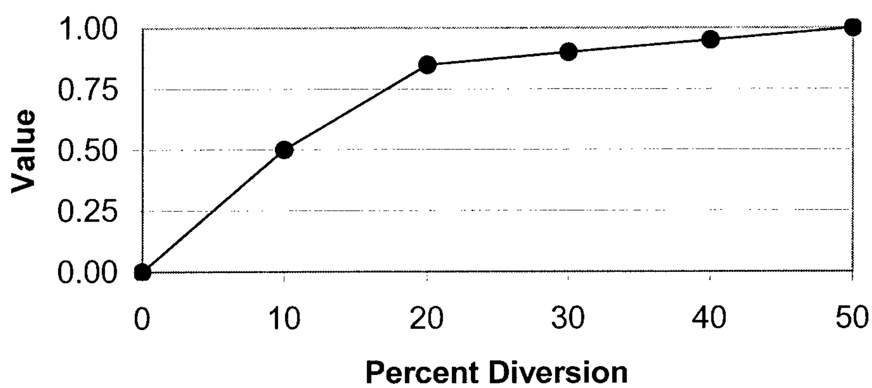


Figure 19. Waste Diversion Value Function

3.4.6 Implementation Time Value Function. The graph in Figure 20 converts each alternative's implementation time in years into value units. Implementation time includes the complete acquisition process (from the beginning of design to completed construction) for a new MSW system. The DM believes the best-case scenario of a 1-year implementation time would occur if the project only involves a landfill since some preliminary landfill site investigative work has already been completed. The DM considers the worst-case scenario of a 6-year implementation time would occur if the project is bumped into the military construction (MILCON) program. These extremes were assigned values of 1 and 0, respectively. From 1 to 2 years, there is only a slight decrease in the implementation time value because the DM views this range as a reasonable implementation time that the state regulators will approve. However, the value drops considerably each year after 2 years because state regulators are less likely to accept the proposed implementation.

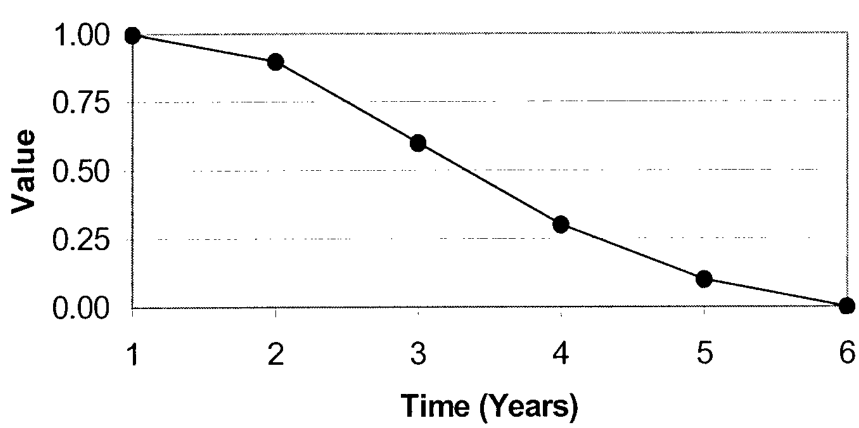


Figure 20. Implementation Time Value Function

3.4.7 CEV Overhead Value Function. Overhead is considered to be the amount of time, measured in manhours, spent by 611 CES Environmental Flight personnel working on Eareckson's MSW issues. The graph in Figure 21 converts each alternative's overhead into value units. Presently, the DM's staff estimates that they spend 40-manhour per year working on Eareckson MSW issues (assuming the site is in compliance). This is their best-case scenario and is assigned a value of 1. For the worst-case scenario, which is assigned a value of 0, the staff envisions their efforts increasing to 160 manhours if they add incinerator, composting, and recycling issues to the current workload involving only landfill issues. Within this range, the DM believes there is a linear relationship between the overhead value and the amount of manhours expended by the staff.

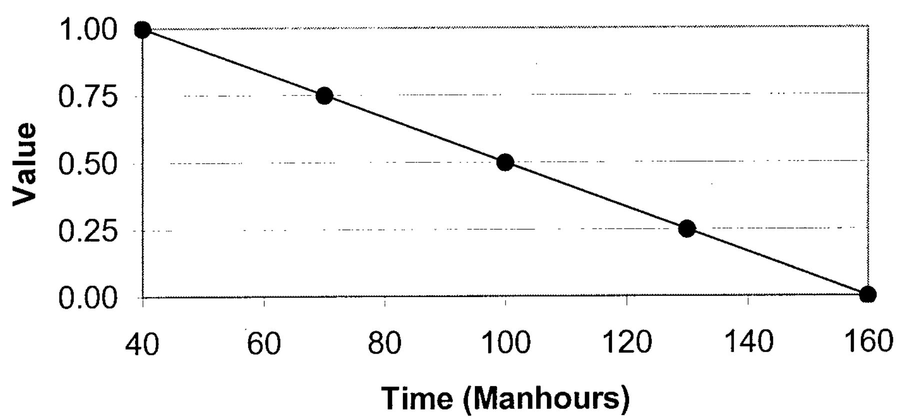


Figure 21. CEV Overhead Value Function

3.4.8 Liability to Air Force. The graph in Figure 22 converts each alternative's estimated future liability to the Air Force, as measured by the number of permits required for MSW operations, into value units. Currently, Eareckson requires two permits for MSW operations, one each for solid waste disposal and water discharge from the landfill. This is considered the best-case scenario and is assigned a value of 1. On the other hand, five permits is the worst-case scenario with a value of 0 for the DM. If three additional permits are required for incinerator air emissions, the composting facility, and the recycling facility, the total number of required permits would be five; this is considered the worst-case scenario and is assigned a value of 0. The DM believes there is a linear relationship between the liability and the number of permits.

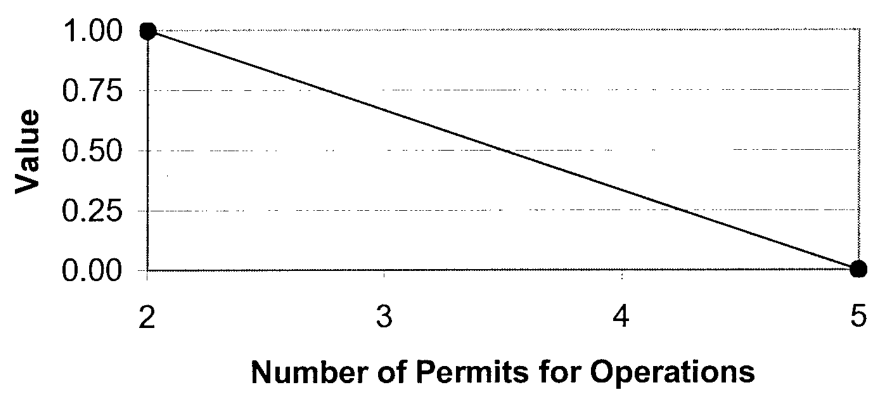


Figure 22. Liability to Air Force Value Function

3.4.9 Impact to Environment Value Function. Unlike the previous eight value functions, the value function for *Impact to Environment* uses a constructed, categorical scale. Figure 23 ranks the different combinations of MSW management techniques from the ISWM hierarchy (recycling, composting, incineration, and landfilling) based upon the DM's perceptions of each combination's environmental impact. The DM thinks that a MSW system consisting of a landfill and a recycling program has the least environmental impact and assigned this scenario a value of 1. Part of the reason for this is that recycling conserves landfill space and does not pose any nuisance potentials like composting does. On the other hand, a MSW system consisting of landfilling and incineration is given a value of 0 since these two components have the most potential for impacting the environment and no materials are being recovered.

Rank	Landfill	Incineration	Composting	Recycling	Value
1 (Best)	x	-	-	x	1
2	x	-	x	x	0.95
3	x	-	x	-	0.90
4	x	x	-	x	0.50
5	x	x	x	x	0.45
6	x	x	x	-	0.40
7	x	-	-	-	0.10
8 (Worst)	x	x	-	-	0

Figure 23. Impact to Environment Value Function

3.5 Step 5 – Objectives Hierarchy Weights

The Eareckson AS objectives hierarchy derived in Step 2 consists of multiple objectives that the decision-making team must consider. However, each of these objectives is not necessarily equally important to the decision-maker. To account for this varying degree of importance of the objectives, the direct weighting technique discussed in Chapter 2 was used to assign weights to the objectives. The direct weighting technique is a direct assessment of the importance of one value over another without considering how much that value actually contributes to the total score of the alternatives (von Winterfeldt and Edwards, 1986: 274). Figure 24 shows the Eareckson AS objectives hierarchy along with the local weights the decision-maker assigned to each objective (global weights are shown in parentheses). As described in Chapter 2, a local weight refers to how much weight a sub-objective contributes to the objective directly above it; a global weight refers to how much weight each of the last-tier objectives in each branch of the objectives hierarchy contributes to the overall objective at the top of the hierarchy. An explanation of how these weights were calculated follows the figure.

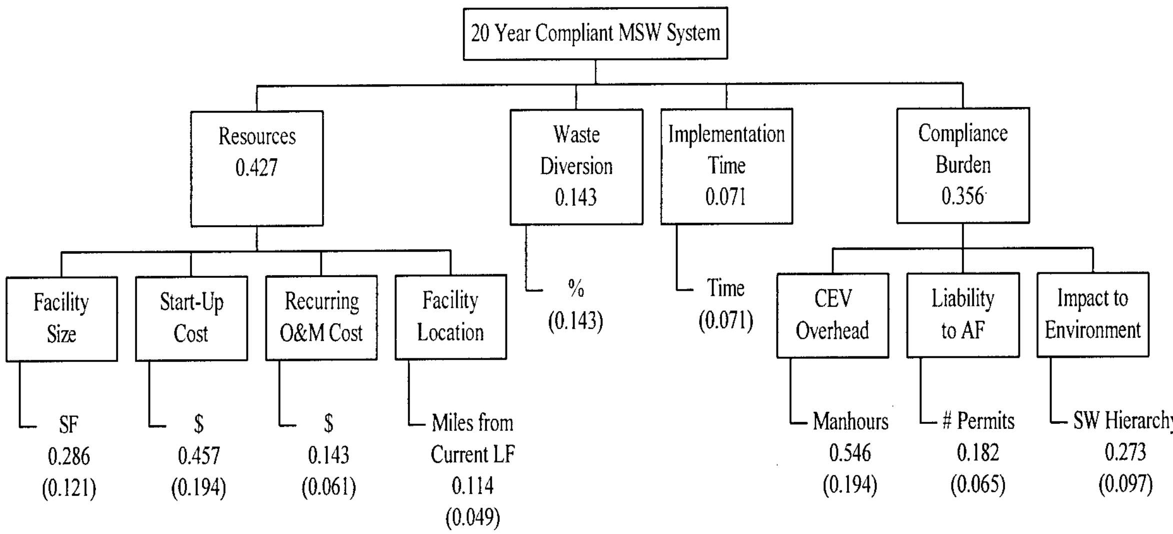


Figure 24. Eareckson AS Objectives Hierarchy With Weights

3.5.1 Local Weights for Resources Sub-Objectives. To calculate how much weight the third-tier objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost*, and *Facility Location* contribute to the second-tier objective *Resources* (the sum of the four weights must equal 1), the following process was used. First, the DM indicated that *Facility Location* was the least valued third-tier objective because a location for a new landfill is a resource the DM already possesses. The second least valued objective was *Recurring O&M Cost*. The DM is not as concerned with O&M cost when compared to start-up cost. O&M funds for the Eareckson BOS contract come from a source that is not part of the DM's budget, while project funds are part of the DM's budget. Of the two remaining objectives, the DM values *Start-Up Cost* more than *Facility Size* since project funds are the most limited resource. After the order of value between the four objectives was established, the DM was asked how much more each of the objectives *Start-Up Cost*, *Recurring O&M Cost*, and *Facility Size* were valued over the least valued objective *Facility Location*. *Recurring O&M Cost* was 1.25 times more valued, *Facility Size* was

2.5 times more preferred, and *Start-Up Cost* was 4 times more valued. Appendix B contains the calculations used to solve for the weight values shown in Figure 24.

3.5.2 Local Weights for Compliance Burden Sub-Objectives. To calculate how much weight the third-tier objectives *CEV Overhead*, *Liability to AF*, and *Impact to Environment* contribute to the second-tier objective *Compliance Burden* (the sum of the three weights must equal 1), the following process was used. First, the DM indicated that *Liability to AF* was the least valued third-tier objective because the CEV staff has a good working relationship with the environmental regulators and is fully capable of managing any Eareckson MSW system recommended by this research. The second least valued objective was *Impact to Environment*, which leaves *CEV Overhead* as the most valued of the three objectives. The DM values *CEV Overhead* more because the CEV staff has many responsibilities and the DM does not want to overburden them with unnecessary additional taskings. After the order of value between the three objectives was established, the DM was asked how much more each of the objectives *CEV Overhead* and *Impact to Environment* were valued over the least preferred objective *Liability to AF*. *CEV Overhead* was 3 times more valued and *Impact to Environment* was 1.5 times more valued. Appendix B contains the calculations used to solve for the weight values shown in Figure 24.

3.5.3 Local Weights for 20-Year Compliant MSW System Sub-Objectives. To calculate how much weight the second-tier objectives *Resources*, *Waste Diversion*, *Implementation Time*, and *Compliance Burden* contribute to the first-tier objective *20-Year Compliant MSW System* (the sum of the four weights must equal 1), the following process was used. First, the DM indicated that *Implementation Time* was the least valued

second-tier objective because of high confidence that a new MSW system can be implemented within a state regulator-approved timeframe. The second least valued objective was *Waste Diversion*. As much as the DM would like to achieve the AF diversion goals, resources and compliance burden are much more valuable objectives. Of the two remaining objectives, the DM was almost indifferent between the two, but selected *Resources* as more valued than *Compliance Burden*. After the order of value preference between the four objectives was established, the DM was asked how much more each of the objectives *Resources*, *Waste Diversion*, and *Compliance Burden* were valued over the least preferred objective *Implementation Time*. *Waste Diversion* was 2 times more valued, *Compliance Burden* was 5 times more valued, and *Resources* was 6 times more valued. Appendix B contains the calculations used to solve for the weight values shown in Figure 24.

3.5.4 Global Weights for Last-Tier Objectives. Data obtained during the determination of local weights may also be used to determine the global weights. Appendix B contains the calculations used to solve for these weight values (also shown in Figure 24).

3.6 Step 6 – Alternative Generation

The purpose of this section is to discuss the process used to develop the alternatives to be evaluated with this model. To more efficiently utilize the limited time of the decision-maker and the CEV staff, a draft strategy generation table was developed from the literature review presented in Chapter 2. Shown in Table 10, the draft strategy generation table was presented to the decision-making team. Upon review of the draft

table, the team developed some basic assumptions and constraints which resulted in changes to the strategy generation table. The team's assumptions and constraints, sorted by MSW management technique, are discussed below.

Table 10. Draft Strategy Generation Table

Landfills	Incineration	Recycling	Composting
Class II MSWLF	Modular	Aluminum Cans	Vermiculture
Class II MSWLF without liner and leachate collection	Mass-Burn	Paper	Windrow
Class III MSWLF	RDF	Glass	Aerated Static Pile
	None	Plastic	In-Vessel
		Metals	None
		None	

3.6.1 Landfill Assumptions and Constraints. Since there will always be waste that cannot be recycled, composted, or incinerated, every alternative evaluated in this research will include a landfill. Additionally, any alternative that includes a Class III MSWLF must also include an incinerator because Eareckson cannot qualify for Class III status under State of Alaska regulations without an incineration program. There are three potential landfill locations: (1) the current landfill site which state regulators identified as a possible Class III landfill if an incineration program was initiated (ADEC, 2000b), (2) Location A near the current landfill, and (3) Location B adjacent to the old taxiway. Locations A and B were identified in a recent landfill site selection study (Jacobs, 2000).

3.6.2 Incineration Assumptions and Constraints. After a great deal of discussion, the decision-making team decided that only incinerator technologies with a charging capacity less than 5 tons per day should be evaluated. The primary reason for

this constraint is that air emissions calculations are based upon the maximum daily charging capacity of the incinerator and not on the actual use of the incinerator. A secondary reason is that Eareckson currently generates less than a ton per day of waste and this capacity will minimize accumulation time before burning is required. The literature review for this thesis revealed that no mass-burn or RDF incinerators exist with a charging capacity as low as 5 tons per day. Therefore, these two incineration technologies were eliminated from the strategy generation table by the team.

3.6.3 Recycling Assumptions and Constraints. The following assumptions were made regarding the establishment of a recycling program. First, it is assumed that all materials will be backhauled on military cargo planes to the Elmendorf Air Force Base (AFB) recycling center on a space available basis. Second, the team eliminated plastics recycling as an option because there are no recycling processors in Alaska that accept plastics. Third, scrap metals were dropped from the options list because Eareckson already recycles this waste component by stockpiling the material at a designated location; it is assumed that stockpiling of this material will continue. Fourth, newspaper, office paper, and mixed paper may be considered as a single waste stream (paper) since the Elmendorf AFB recycling center mixes these paper wastes. The recycling center shreds the paper waste to form a feedstock for a windrow composting operation and for horse stable bedding (Paige, 2000). Fifth, glass does not need to be separated by color since the material will be crushed with a glass pulverizer. Sixth, since aluminum and steel cans use the same processing equipment, the team feels that these two items should be combined into one category (Aluminum/Steel Cans).

3.6.4 Composting Assumptions and Constraints. The 611 CES specified a desire for a composting system with a charging capacity no less than 200 lbs per day and no greater than 1000 lbs per day. This constraint eliminates vermiculture composting because the typical vermiculture composting unit will only process 20 lbs per day (EPM Inc., 2). While there once were large-scale vermin-composting systems, there are no such facilities currently in operation in the United States (Hickman, 1999: 315). Another requirement expressed by the 611 CES was that a composting system must be containerized due to animal control and persistent high wind conditions. These two constraints eliminate windrow, aerated static pile, and anaerobic composting technologies.

3.6.5 Political Assumptions and Constraints. The decision-making team made a few basic assumptions and constraints regarding waste that could be addressed by a number of different MSW management techniques. For example, it was assumed that food waste may be composted, incinerated, or landfilled. The team further assumed that the ISWM hierarchy would be used to select the most preferred MSW management technique. Thus, for food waste, composting would be the MSW management technique used to address this waste stream component since it is higher on the ISWM hierarchy. However, the decision-making team did make three exceptions to this rule. (1) For alternatives that include incineration, combusting paper and cardboard is preferable to recycling because incineration is done at Eareckson AS while recycling requires packaging and shipping the material to Elmendorf AFB. The team believes incineration requires much less effort than recycling would. Thus, when an alternative includes incineration, recycling paper and cardboard is not an option. (2) For alternatives that

include composting, composting paper is preferable to recycling because composting is done at Eareckson AS while recycling requires packaging and shipping the material to Elmendorf AFB. Thus, when an alternative includes composting, recycling paper is not an option. (3) For alternatives that include incineration and composting, paper will be incinerated because of the greater reduction in volume achieved by incineration. In addition, paper does not quickly biodegrade in composting systems.

3.6.6 Summary of Eareckson AS MSW Alternatives. After incorporating the decision-making team's assumptions, the final strategy table shown in Table 11 was developed to generate alternatives. All combinations of waste management options that meet the constraints identified above will be considered. This represents a total of 112 feasible alternatives.

Table 11. Strategy Generation Table

Landfills	Incinerators	Recycling	Composting
Class III MSWLF @ Current Landfill Location	Modular	Aluminum/Steel Cans	In-Vessel
Build New Class II MSWLF @ Location A	None	Glass	None
Build New Class II MSWLF @ Location B		Paper	
Build New Class III MSWLF @ Location A		Cardboard	
Build New Class III MSWLF @ Location B		None	

Chapter 4. Data Collection & Analysis of Results

This chapter presents the data collection and analysis portion of the Eareckson Air Station (AS) deterministic decision support model. The alternatives to be evaluated with the model are described in more detail and the characterization of the Eareckson Air Station (AS) municipal solid waste (MSW) stream, the data utilized in several of the model evaluation measures, is discussed. The data required for each evaluation measure and the data collected to score each alternative is then presented with the total value and rank of each alternative determined by the model. Finally, the chapter presents results from a deterministic sensitivity analysis to illustrate the sensitivity (or insensitivity) of the highest ranked MSW strategies to changes in the objective weights and to provide insight into which evaluation measures have the most impact on the overall rankings.

4.1 Alternative Analysis

Step 6 of the methodology, presented in Chapter 3, identified a total of 112 possible alternatives that meet the decision-maker's assumptions and constraints. To further reduce the number of feasible alternatives to be evaluated by the model, alternatives that will always be dominated by other alternatives will be eliminated. First, it should be recognized that an alternative, *x,* containing landfill location A will always dominate an alternative, *y*, containing landfill location B when all other MSW techniques included in alternatives *x* and *y* are the same. The alternative with location A will receive the same score as location B in six of the nine model objectives and will always score higher in the *Facility Location*, *Start-Up Cost*, and *Recurring O&M Cost*

objectives; therefore, there are no added benefits for a landfill at location B. Since there will always be an alternative at location A that is better than an alternative at location B, all alternatives with landfill location B will not be evaluated by the model. Second, an alternative, *r*, containing a Class III landfill at the current landfill location will always dominate alternatives *s* and *t* containing a Class III landfill at locations A and B, respectively, when all other MSW techniques included in alternatives *r*, *s*, and *t* are the same. This is because there are no added benefits for a Class III landfill at either locations A or B. Since there will always be an alternative with a Class III landfill at the current landfill location that is better than an alternative with a Class III landfill at either locations A or B, all alternatives with a Class III landfill at locations A or B will not be evaluated by the model. These two observations reduce the number of alternatives to be evaluated by the Eareckson AS decision support model from 112 to 40. Appendix C contains a list of these 40 alternatives.

4.2 Eareckson AS Waste Stream Characterization

To determine the quantity and percentage composition of each component in the overall waste stream, the characterization of the Eareckson AS MSW stream needs to be known. The last solid waste characterization study conducted at Eareckson AS was completed in 1992 when a large military population resided at the site. The 1992 solid waste baseline was 1,904,054 pounds, with an annual average population of 750 personnel (Law Environmental Inc., 1994). When operations at the installation were significantly reduced in 1994, daily operations and maintenance activities for Eareckson AS were transferred to a base operations support (BOS) contract. The current annual

population now averages about 116 people (PACAF, 2000). Because of these significant changes, the results of the 1992 study are no longer valid. To establish reliable waste composition data, Appendix D contains the waste stream characterization study plan used to determine the quantity and percentage composition of each component in the current overall waste stream at Eareckson AS. Table 12 presents the results of this study.

Table 12. Eareckson AS Waste Stream Characterization

Component	Weight in Pounds			Weight Percent
	Study Total	Daily Average	Annual Estimate	
Paper Products:				
High Grade Office	19.2	6.4	2,336.0	0.9
Cardboard	397.0	132.3	48,301.7	17.8
Newspaper	1.5	0.5	182.5	0.1
Magazines	43.6	14.5	5,304.7	2.0
Mixed	161.0	53.7	19,588.3	7.2
Food Waste:	1,067.8	355.9	129,915.7	47.9
Containers:				
Glass	217.6	72.5	26,474.7	9.8
Aluminum	36.5	12.2	4,440.8	1.6
Bi-metal/Tin	67.5	22.5	8,212.5	3.0
Plastic PETE (1)	18.0	6.0	2,190.0	0.8
Plastic HDPE (2)	7.8	2.6	949.0	0.4
Other Plastics:	73.3	24.4	8,906.0	3.2
Metals:				
Ferrous	5.5	1.8	669.2	0.2
Nonferrous	14	4.7	1,703.3	0.6
Other	23	7.7	2,810.5	1
Wood:	17.5	5.8	2,129.2	0.8
Miscellaneous:				
Textiles	17.8	5.9	2,165.7	0.8
Rubber	11.7	3.9	1,423.5	0.5
Leather	1.8	0.6	219.0	0.1
Dirt, ashes, etc.	25.3	8.4	3,078.2	1.1
Total:	**2,227.4**	**742.5**	**271,000**	**100%**

4.3 Step 7 – Alternative Scoring

To score the alternatives generated in Step 6 of the Eareckson AS decision support model, data required for each evaluation measure needs to be collected. This section discusses the relevant data and how it was collected and then provides the data for each alternative.

4.3.1 Data for Facility Size. The evaluation measure for the objective *Facility Size* is the square footage required for a new MSWLF. There are several variables affecting this calculation: landfill depth, daily waste-to-soil cover ratio, final soil cap requirements, landfill waste disposal rate, density of compacted waste material once landfilled, and future growth. Jacobs' (2000) landfill siting study estimates the maximum landfill depth at Eareckson AS is 10 feet due to soil conditions and groundwater depth. Typical waste-to-soil ratios used to estimate the amount of soil necessary for daily landfill cover material range from 2:1 to 5:1 on a volumetric basis (EPA, 1995: 9-13); a ratio of 2:1 is used for the purposes of this analysis. Once the landfill is complete, the final cover requirement is 2 feet of soil in accordance with 18 AAC 60 (1999). The landfill waste disposal rate depends on how much waste is generated and how much is being diverted or reduced by recycling, composting, and incineration operations. The Eareckson AS waste stream characterization data presented earlier in Table 12 will be used in making this assessment. The density of the waste once it is landfilled will be estimated using the data in Table 12 along with compaction factors for each component found in Tchobanoglous *et al.* (1993: 474-475). Since Eareckson AS does not use a compactor during landfill operations, the worst compaction factors were assumed. Finally, there is a possibility that operations at Eareckson may double in the future

(McCloud, 2000). Thus, a safety factor of two will be assumed in the model to account for this potential growth. After incorporating these factors, Table 12 presents the estimated landfill footprint for each of the 40 MSW management alternatives identified in Appendix C. Appendix E contains the assumptions and model used to calculate the square footages shown in this table.

Table 13. Square Footage Data for Facility Size Objective

Alternative	Estimated Landfill Footprint (SF)	Alternative	Estimated Landfill Footprint (SF)
1	50,348	21	115,620
2	46,888	22	100,462
3	38,651	23	102,609
4	35,191	24	112,159
5	48,201	25	94,373
6	44,740	26	103,923
7	36,504	27	69,247
8	33,043	28	90,912
9	50,348	29	100,462
10	46,888	30	65,786
11	38,651	31	57,550
12	35,191	32	54,089
13	48,201	33	84,594
14	44,740	34	81,133
15	36,504	35	72,897
16	33,043	36	84,594
17	115,620	37	69,436
18	112,159	38	81,133
19	103,923	39	72,897
20	106,070	40	69,436

4.3.2 Data for Start-Up Cost. The evaluation measure for the objective *Start-Up Cost* is the initial cost in dollars to implement the MSW management alternative selected. Data required for this evaluation includes equipment, transportation, and construction costs. The Eareckson AS waste stream characterization data presented in Table 12 was used to determine equipment requirements and the magnitude of construction for each alternative under consideration. Cost data used in the model was derived from a number of sources, including vendor estimates, industry estimating data (RS Means), 611 CES Environmental Flight personnel, and recent cost estimates completed for the 611 CES on Eareckson Air Station's waste management system (Jacobs, 2000; United States Army Corps of Engineers, 2000; and Earth Tech, Inc., 1998). Table 14 presents an order-of-magnitude cost estimate for each of the 40 MSW management alternatives identified in Appendix C. Appendix F contains the assumptions and cost estimation model used in developing this table.

Table 14. **Cost Data for Start-Up Cost Objective**

Alternative	Cost Estimate	Alternative	Cost Estimate
1	$1,634,221	21	$1,377,682
2	$1,634,254	22	$1,289,715
3	$1,601,609	23	$1,282,433
4	$1,600,237	24	$1,352,352
5	$1,983,753	25	$1,229,627
6	$1,983,786	26	$1,315,049
7	$1,951,141	27	$1,038,090
8	$1,949,769	28	$1,219,784
9	$1,759,492	29	$1,289,715
10	$1,751,023	30	$1,012,738
11	$1,698,121	31	$975,378
12	$1,688,230	32	$950,017
13	$2,103,747	33	$1,493,610
14	$2,095,275	34	$1,485,166
15	$2,042,366	35	$1,432,336
16	$2,032,472	36	$1,510,509
17	$1,360,783	37	$1,422,481
18	$1,352,352	38	$1,485,166
19	$1,299,554	39	$1,447,831
20	$1,292,272	40	$1,422,481

4.3.3 Data for Recurring O&M Cost. The evaluation measure for the objective *Recurring O&M Cost* is the cost in year 2000 dollars to operate and maintain the MSW management alternative. Cost data used in the model was derived from a number of sources, including industry estimates, 611 CES environmental flight personnel, Eareckson AS contractor personnel, and recent cost estimates completed for the 611 CES on Eareckson Air Station's waste management system (Jacobs, 2000; United States Army Corps of Engineers, 2000; and Earth Tech, Inc., 1998). Table 15 presents O&M cost estimates for each of the 40 MSW management alternatives identified in Appendix C.

Appendix G contains the assumptions and cost estimation model used in developing this table.

Table 15. Cost Data for Recurring O&M Cost Objective

Alternative	Cost Estimate	Alternative	Cost Estimate
1	$15,396	21	$33,371
2	$15,042	22	$33,367
3	$17,291	23	$33,116
4	$16,938	24	$33,017
5	$20,829	25	$35,365
6	$20,476	26	$35,266
7	$22,725	27	$33,663
8	$22,372	28	$35,012
9	$35,396	29	$34,913
10	$35,042	30	$33,310
11	$37,291	31	$35,559
12	$36,938	32	$35,205
13	$40,829	33	$38,208
14	$40,476	34	$37,854
15	$42,725	35	$40,103
16	$42,372	36	$39,753
17	$31,825	37	$39,750
18	$31,472	38	$39,400
19	$33,721	39	$41,649
20	$33,470	40	$41,295

4.3.4 Data for Landfill Location. The evaluation measure for the objective *Landfill Location* is distance in miles from the current landfill location. As previously discussed, the decision-maker identified three potential landfill locations: the current landfill site and Locations A and B identified in a recent landfill site selection study (Jacobs, 2000). Table 16 presents the distance from the current landfill for each of these

locations. Recall that all alternatives with a landfill at Location B were eliminated from the model since alternatives with a landfill at Location A will always dominate.

Table 16. Mileage Data for Landfill Location Objective

Location	Miles from Current Landfill	Alternatives
Current Landfill	0	1 through 8
Location A	0.5	9 through 40
Location B	3.0	NA

4.3.5 Data for Waste Diversion. The evaluation measure for the objective *Waste Diversion* is the percentage of solid waste diverted from landfill and incinerator facilities through recycling and composting operations. To assess how much waste is diverted by these waste management techniques, the components to be recycled and/or composted need to be selected. (Chapter 2 provides background on which components may be recycled and composted and the strategy generation table in Chapter 3 identifies the waste stream components that Eareckson AS is considering recycling.) In addition, the quantity of each component as well as its composition percentage in the overall waste stream must be known. Furthermore, even if a component is recycled or composted, it is unrealistic to believe that 100 percent of the waste component will be diverted. Thus, a reasonable diversion rate for each component must be estimated as well. A recovery rate of 80 percent was assumed in the model (McCloud, 2000). The Eareckson AS waste stream characterization data presented in Table 12 was used to estimate the amount of materials diverted by recycling and composting operations for each alternative. Table 17 presents the estimated percentage of waste diversion for each of the 40 MSW

management alternatives identified in Appendix C. Appendix H contains the assumptions and model used to generate the percentages in this table.

Table 17. Percentage Waste Diversion Data for Waste Diversion Objective

Alternative	Waste Diversion (%)	Alternative	Waste Diversion (%)
1	0.0%	21	14.3%
2	3.7%	22	11.6%
3	7.8%	23	10.3%
4	11.6%	24	18.0%
5	38.4%	25	14.3%
6	42.1%	26	22.1%
7	46.2%	27	20.8%
8	49.9%	28	18.1%
9	0.0%	29	25.8%
10	3.7%	30	24.5%
11	7.8%	31	28.6%
12	11.6%	32	32.3%
13	38.4%	33	44.9%
14	42.1%	34	48.6%
15	46.2%	35	52.7%
16	49.9%	36	59.1%
17	0.0%	37	56.4%
18	3.7%	38	62.9%
19	7.8%	39	67.0%
20	6.5%	40	70.7%

4.3.6 Data for Implementation Time. The evaluation measure for the objective *Implementation Time* is the time required to fully implement the MSW management alternative. Table 18 presents implementation time estimates provided by the CEV staff for each of the 40 MSW management alternatives identified in Appendix C. Implementation times are based on April 2001 being the earliest start time and it is assumed that the entire MSW management alternative will be implemented during the same timeframe.

Table 18. Time Data for Implementation Time Objective

Alternative	Implementation Time (yrs)	Alternative	Implementation Time (yrs)
1	3.5	21	1.5
2	3.5	22	1.5
3	3.5	23	1.5
4	3.5	24	1.5
5	3.5	25	1.5
6	3.5	26	1.5
7	3.5	27	1.5
8	3.5	28	1.5
9	3.5	29	1.5
10	3.5	30	1.5
11	3.5	31	1.5
12	3.5	32	1.5
13	3.5	33	2.5
14	3.5	34	2.5
15	3.5	35	2.5
16	3.5	36	2.5
17	1.5	37	2.5
18	1.5	38	2.5
19	1.5	39	2.5
20	1.5	40	2.5

4.3.7 Data for CEV Overhead. The evaluation measure for the objective *CEV Overhead* is the number of manhours spent by the 611 CES Environmental Flight on Eareckson AS MSW management issues. Table 19 presents manhour estimates provided by the CEV staff for each of the 40 MSW management alternatives identified in Appendix C.

Table 19. Manhour Data for CEV Overhead Objective

Alternative	Overhead (MHs)	Alternative	Overhead (MHs)
1	90	21	66
2	106	22	66
3	106	23	66
4	106	24	66
5	114	25	66
6	130	26	66
7	130	27	66
8	130	28	66
9	100	29	66
10	116	30	66
11	116	31	66
12	116	32	66
13	124	33	74
14	140	34	90
15	140	35	90
16	140	36	90
17	50	37	90
18	66	38	90
19	66	39	90
20	66	40	90

4.3.8 Data for Liability to Air Force. The evaluation measure for the objective *Liability to AF* is the number of permits required to operate the MSW system. Table 20 presents the permit estimates provided by the CEV staff for each of the 40 MSW management alternatives identified in Appendix C.

Table 20. Number of Permits Data for Liability to AF Objective

Alternative	AF Liability (Number of Permits)	Alternative	AF Liability (Number of Permits)
1	3	21	2
2	3	22	2
3	3	23	2
4	3	24	2
5	4	25	2
6	4	26	2
7	4	27	2
8	4	28	2
9	3	29	2
10	3	30	2
11	3	31	2
12	3	32	2
13	4	33	3
14	4	34	3
15	4	35	3
16	4	36	3
17	2	37	3
18	2	38	3
19	2	39	3
20	2	40	3

4.3.9 Data for Impact to Environment. The evaluation measure for the objective *Impact to Environment* is a constructed measure based on the integrated solid waste management hierarchy. Figure 14 in Chapter 3 categorizes the different combinations of MSW management techniques from the ISWM hierarchy (recycling, composting, incineration, and landfilling). Table 21 presents the category for each of the 40 MSW management alternatives identified in Appendix C.

Table 21. Category Data for Impact to Environment Objective

Alternative	Impact to Env (category)	Alternative	Impact to Env (category)
1	8	21	1
2	4	22	1
3	4	23	1
4	4	24	1
5	6	25	1
6	5	26	1
7	5	27	1
8	5	28	1
9	8	29	1
10	4	30	1
11	4	31	1
12	4	32	1
13	6	33	3
14	5	34	2
15	5	35	2
16	5	36	2
17	7	37	2
18	1	38	2
19	1	39	2
20	1	40	2

Note: 1 and 8 represent the least and most environmental impact, respectively.

4.4 Step 8 – Deterministic Analysis

This section presents the deterministic results of the Eareckson AS MSW decision support model. First, the overall value and respective ranking of each alternative as determined by the model are presented. Next, insight is provided into why the top 4 model alternatives scored so well compared to the other 36 model alternatives.

4.4.1 Overall Value and Ranking of Alternatives. The data collected from Steps 4 (value functions), 5 (weights), and 7 (alternative scoring) were used in the decision model found in Appendix K and an overall, additive value function was used to calculate the overall value of each alternative. As discussed in Chapter 2, the additive value function is simply a weighted average of the various objective value functions. The overall value function rank orders the model alternatives in a way that is consistent with the decision-maker's preferences for those outcomes.

Figure 25 presents the ranking of the 40 alternatives under evaluation by the model based on the overall value received for the strategic objective *20-Year Compliant MSW System*. In addition, Figure 25 qualitatively shows how much value each of the decision-maker's nine bottom-tier objectives contribute to a particular alternative's overall value (the actual values for each objective are provided at the end of Appendix K). A hypothetical best-case alternative is included at the top of the graph to illustrate the maximum contribution each objective could possibly have on the overall value. Note that not all of the bottom-tier objectives necessarily contribute to the overall value for an alternative. For example, if an alternative does not include recycling or composting operations, then the waste diversion objective was considered to have no value associated

with it; therefore, the portion of the bar representing the waste diversion objective would not be present on the graph for this particular alternative.

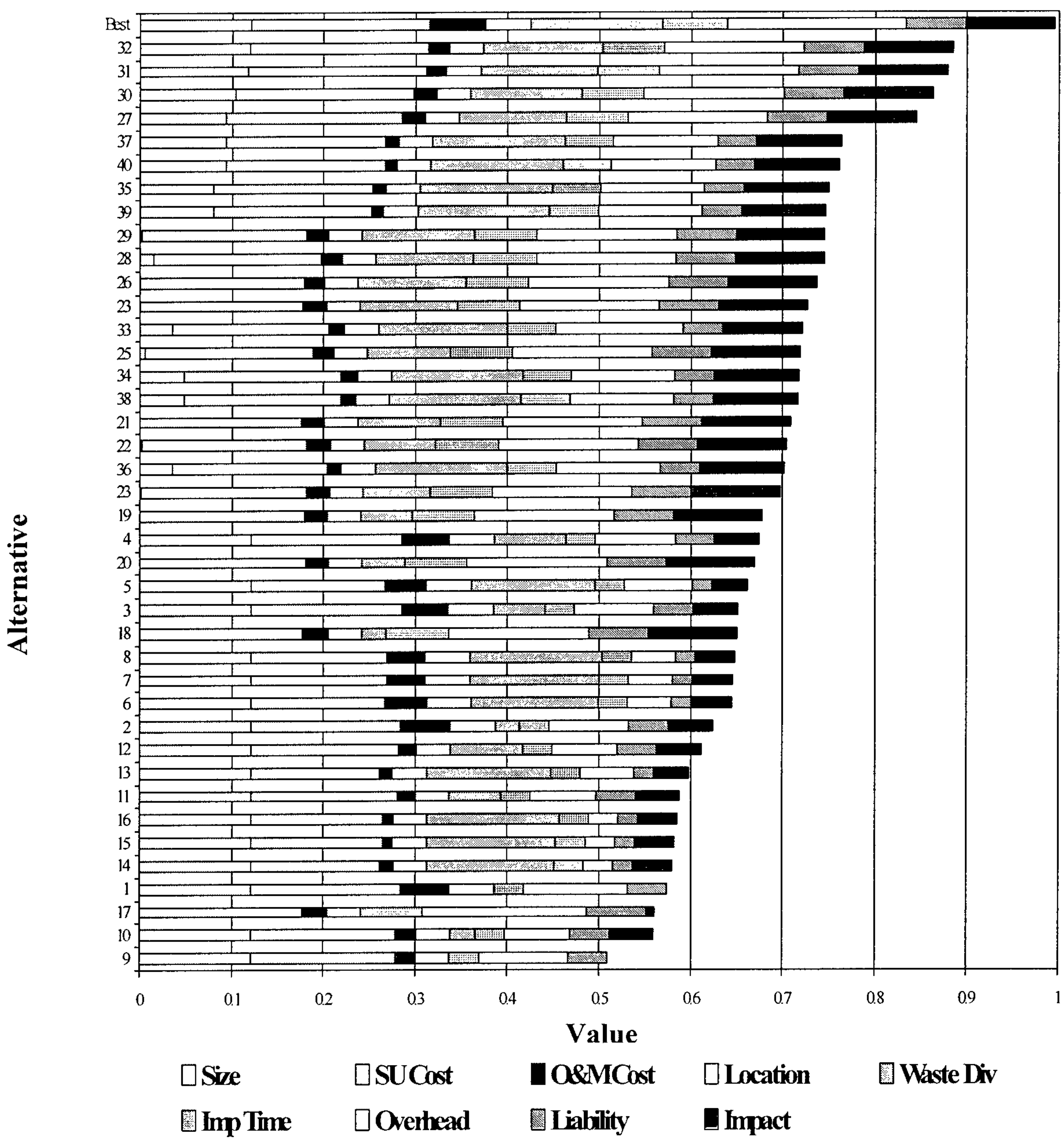


Figure 25. Overall Value Ranking (by Bottom Tier Objectives)

4.4.2 Insight Into Top Model Alternatives. Figure 25 shows four alternatives (32, 31, 30, and 27) that clearly provide the greatest overall value to the decision-maker. Comparing the bars on the graph in Figure 25 for these top alternatives with the hypothetical best-case alternative, it is apparent the top alternatives scored high in almost all of the measures. The top alternatives scored particularly high on the measures for the four most heavily weighted objectives (*Facility Size*, *Start-Up Cost*, *Waste Diversion*, and *CEV Overhead*), which account for 65 percent of the total possible value. Table 22 summarizes the MSW management techniques, technologies, and management programs that are included in the top four alternatives. From this figure, it is discovered that these four alternatives all contain a Class II landfill, no incineration or composting, and some combination of recycling.

Table 22. Eareckson AS Decision Support Model Top

Alternative	Description
32	Class II MSWLF, Recycle Aluminum & Steel Cans, Recycle Glass, Recycle Paper, and Recycle Cardboard
31	Class II MSWLF, Recycle Glass, Recycle Paper, and Recycle Cardboard
30	Class II MSWLF, Recycle Aluminum & Steel Cans, Recycle Paper, and Recycle Cardboard
27	Class II MSWLF, Recycle Paper, and Recycle Cardboard

The model results are somewhat surprising considering that the 611 CES/CEV staff were seriously considering an alternative with composting or an alternative with a Class III landfill and incinerator before the decision-making process for this research began. Upon close evaluation of the weights for each objective, the value functions, and the measure scores for each of the alternatives, one can gain insight into why the top

ranked alternatives include a Class II MSWLF and recycling operations for paper and cardboard. In addition, one can see why 22 out of 24 alternatives containing a Class II MSWLF with no incineration program outperformed the 16 alternatives that included an incinerator facility. A number of observations regarding the MSW at Eareckson support these results. First, paper and cardboard account for nearly 26 percent of the Eareckson AS waste stream by weight. Recycling and incineration of these items results in 0.91 and 0.0 value points, respectively, for the *Waste Diversion* objective (before weighting). This objective is the third most heavily weighted one and accounts for a maximum of 14.3 percent of the total possible value for an alternative. Since alternatives containing a Class III MSWLF must also include an incinerator, and the decision-maker determined that all combustibles will be combusted if an incinerator is present, these alternative can only receive minimal value points for this objective compared to Class II MSWLF alternatives containing recycling operations for paper and cardboard. Second, paper and cardboard account for nearly 54 percent of the Eareckson AS waste stream by volume. By diverting such a large percentage of the waste stream away from landfill disposal, a much smaller landfill footprint is required. Therefore, alternatives including paper and cardboard recycling receive at least 0.77 value points for the *Facility Size* objective (before weighting). This objective is the fourth most heavily weighted one and accounts for a maximum of 12.1 percent of the total possible value for an alternative. Third, there is a direct relationship between facility size and the landfill portion of total start-up cost. Since the savings associated with building a smaller landfill facility due to recycling paper and cardboard far outweighs the cost of implementing a paper and cardboard recycling program, alternatives containing a Class II MSWLF with no incinerator or

composting operations receive nearly the maximum value points for the *Start-Up Cost* objective. On the other hand, alternatives containing a Class III landfill receive far less value for this objective in spite of a reduced facility size because of the cost of the incinerator facility these alternatives must include. This objective is tied with *CEV Overhead* as the most heavily weighted objective and accounts for 19.4 percent of the total possible value points. Finally, alternatives that include only landfilling and recycling receive the maximum possible value points (1.0) for the *CEV Overhead* objective (before weighting), while alternatives that include incineration receive no higher than 0.5 value points. This objective is tied with *Start-Up Cost* as the most heavily weighted objective and accounts for 19.4 percent of the total possible value points.

4.5 Step 9 – Sensitivity Analysis

Sensitivity analysis is used to determine the impact on the ranking of alternatives caused by changes in various model assumptions. This section presents the results of sensitivity analysis conducted on the objectives hierarchy weights and on some of the key model parameters. To assess whether the top ranked alternative(s) would have been different had the decision-maker weighted the objectives differently, weighting sensitivity analyses were performed on three different set of values: (1) the global weights of the nine bottom-tier objectives; (2) the local weights of the third-tier objectives; and (3) the local weights of the second-tier objectives. In addition, sensitivity analysis was conducted on landfill depth, recovery ratio, and MSW generation rate, key

model parameters for which the model uses deterministic point estimates, since there is a considerable amount of uncertainty associated with these parameters.

4.5.1 Global Weights Sensitivity. Global weight sensitivity analysis was performed on the nine bottom-tier objectives to determine the impact on the ranking of alternatives as the nominal weight of a specific bottom-tier objective was allowed to range from 0 to 100 percent of the overall objective weight. As an objective's weight is varied, the weights of other bottom-tier objectives are changed proportionally to ensure the sum of the global weights remain one. With this type of sensitivity analysis, as the weight of the objective under evaluation approaches 100 percent of the overall weight value, it becomes the dominant objective in the model. At 100 percent of the overall weight value, it is the only objective, and the model becomes a singular objective model. The resulting graphs and associated discussion follow. To make the graphs readable, only the sensitivity results of the top four model alternatives are displayed as well as those alternatives not originally ranked in the top four that become part of the top four alternatives at some point during the sensitivity range.

*4.5.1.1 **Facility Size Global Weight Sensitivity.*** Figure 26 illustrates the sensitivity of the top ranked alternatives to facility size as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the highest ranked alternative over the range from 0 – 0.95. Alternative 4, which has one of the smallest landfill footprints because of the large volume reduction from incineration and recycling, becomes the top ranked alternative only after the facility size weight approaches one. As discussed in the previous section, alternatives that include incineration are not valued as highly by this model. This explains why it takes almost all of the total weight being placed on this single objective before Alternative 32 loses its place as the top-ranked alternative.

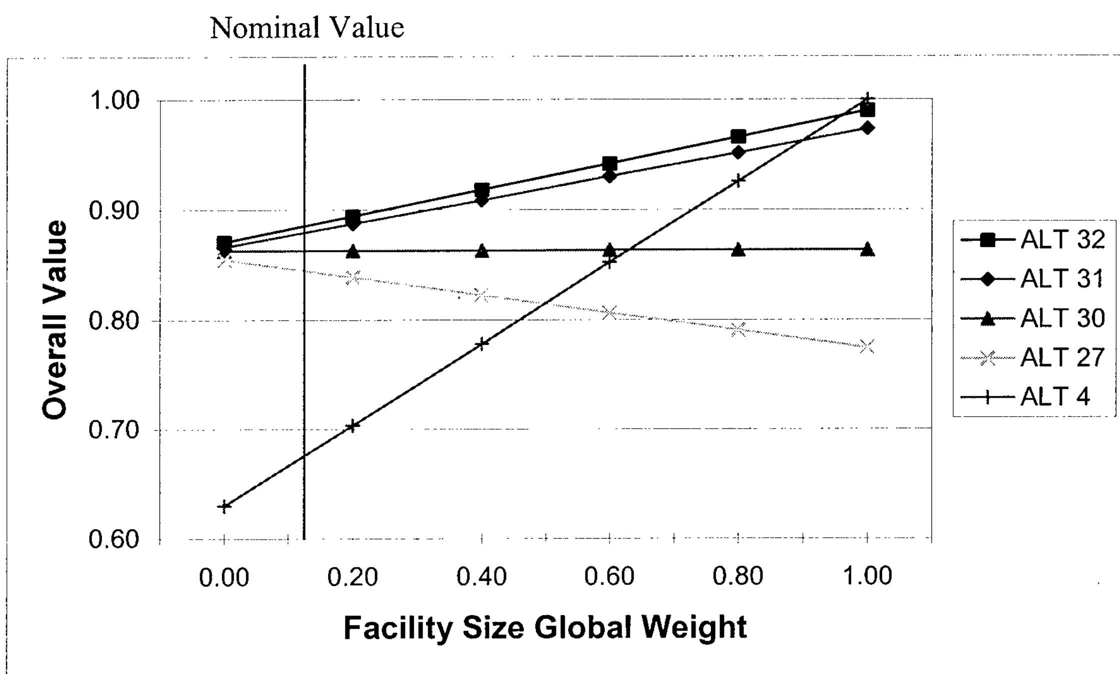


Figure 26. Sensitivity Analysis on Facility Size Global Weight

4.5.1.2 Start-Up Cost Global Weight Sensitivity. Figure 27 illustrates the sensitivity of the top ranked alternatives to the start-up cost as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the highest ranked alternative over the entire range (0 – 1.0). Alternative 32 received the maximum value points (1.0) possible for this objective, so it makes sense that it remains the top alternative as the weight approaches one from the nominal weight value.

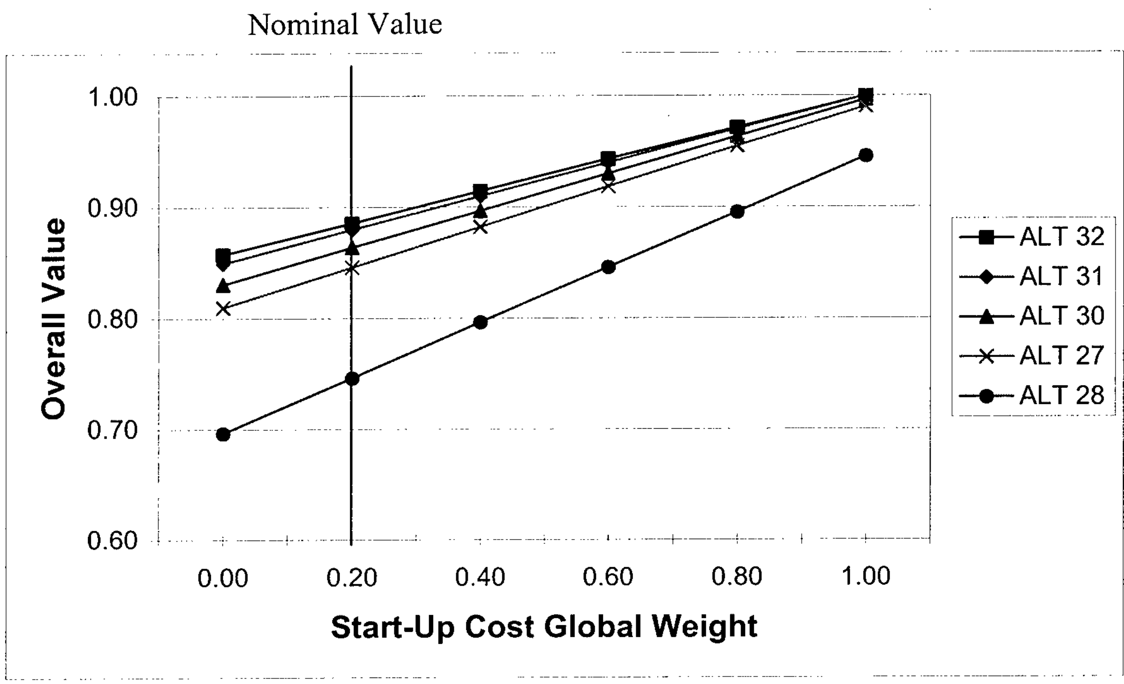


Figure 27. Sensitivity Analysis on Start-Up Cost Global Weight

4.5.1.3 Recurring O&M Cost Global Weight Sensitivity. Figure 28 illustrates the sensitivity of the top ranked alternatives to recurring O&M cost as the bottom-tier objective global weight is varied from 0 to 1. The highest ranked alternatives over their respective ranges are Alternative 32 from 0 to 0.35, Alternative 4 from 0.35 to 0.51, and Alternative 2 from 0.51 to 1.0. At the model's nominal weight values, alternatives with Class III MSWLF, incinerator, and recycling operations (Alternatives 2, 3 and 4 in Figure 28) receive less overall value than alternatives that contain only Class II MSWLF and recycling operations (Alternatives 32, 31, 30, and 27 in Figure 28). However, Alternatives 2, 3, and 4 receive the most value out of the 40 alternatives under evaluation for the objective *Recurring O&M Cost* while Alternatives 32, 31, 30, and 27 receive only a marginal amount of value for this objective. This is because alternatives that contain Class III MSWLF and incineration operations cost less to operate and maintain than alternatives that contain Class II MSWLF and recycling operations mainly due to the high costs associated with Class II MSWLF monitoring and reporting requirements. Thus, as illustrated in the figure, as more weight value is placed on the objective *Recurring O&M Cost*, Alternatives 2, 3, and 4 increase in overall value and Alternatives 32, 31, 30, and 27 decrease in overall value. Alternative 4 takes over Alternative 32 as the top ranked alternative over part of the sensitivity range and then Alternative 2 takes over as the top ranked alternative for the remainder of the range. While both Alternatives 2 and 4 include Class III MSWLF, incineration, and recycling operations, Alternative 2 only includes recycling operations for aluminum/steel cans while Alternative 4 includes recycling operations for aluminum/steel cans and glass.

Apparently, the benefits associated with recycling glass do not outweigh the decrease in O&M cost value associated with glass recycling operations.

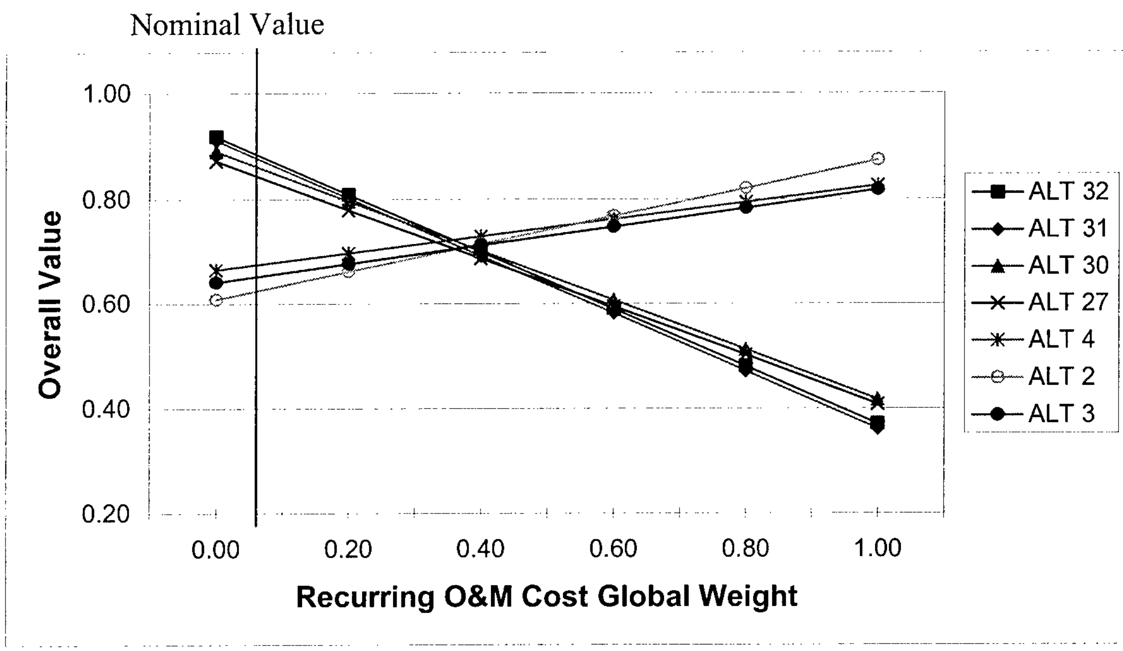


Figure 28. Sensitivity Analysis on Recurring O&M Cost Global Weight

4.5.1.4 Facility Location Global Weight Sensitivity. Figure 29 illustrates the sensitivity of the top ranked alternatives to facility location as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the best alternative over the weight range 0 to 0.49 and Alternative 4 is the highest ranked alternative when the objective weight is greater than 0.49 for facility location. Alternative 4 includes a Class III MSWLF while Alternative 32 has a Class II MSWLF. For the current set of alternatives under evaluation, an alternative with a Class III MSWLF will always receive more value than a Class II MSWLF for this objective because only a Class III landfill can be built at the current landfill location. This model assigns the maximum value of 1.0 for this objective if an alternative's landfill location is at the current landfill site. Thus, once enough weight is placed on this objective, alternatives with a Class III MSWLF (Alternatives 2, 3, and 4 in Figure 29) outperform those with Class II MSWLF (Alternatives 32, 31, 30, and 27 in Figure 29).

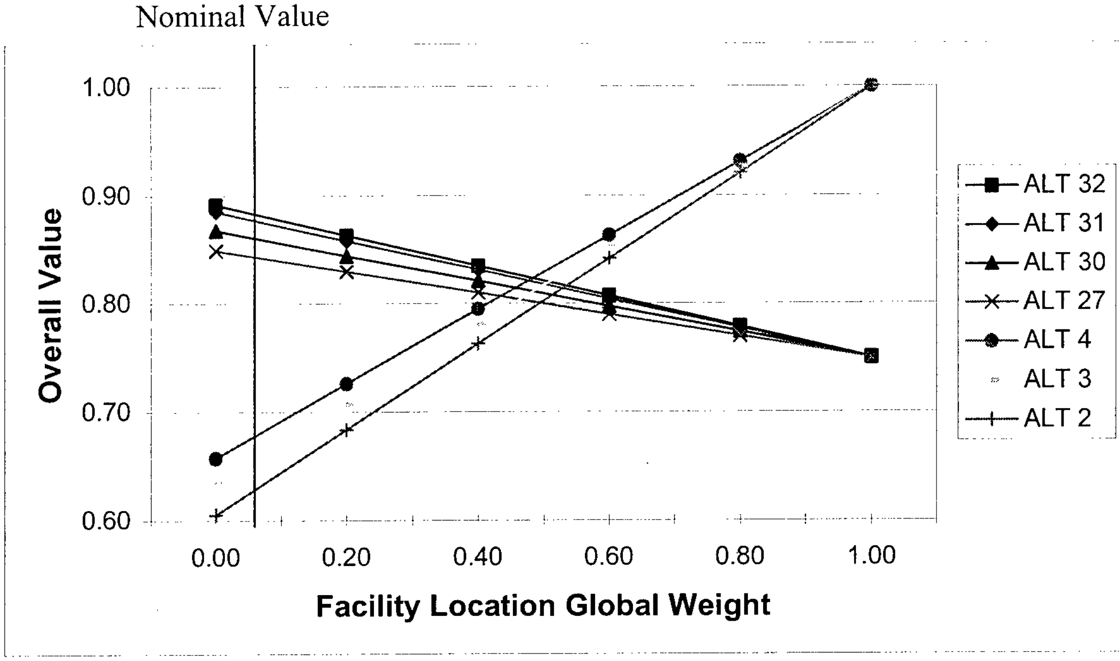


Figure 29. Sensitivity Analysis on Facility Location Global Weight

4.5.1.5 Waste Diversion Global Weight Sensitivity. Figure 30 illustrates the sensitivity of the top ranked alternatives to waste diversion as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the highest ranked alternative over the range from 0 to 0.63. Alternatives 37 and 40 become the top ranked alternatives when the objective weight is greater than 0.63 for waste diversion because these two alternatives divert more solid waste away from landfill and incinerator facilities through recycling and composting operations than Alternative 32 does. While Alternative 32 contains more recycling operations than both Alternatives 37 and 40, these two later alternatives include composting operations. Alternatives 37 and 40 receive the maximum possible value (1.0) for this objective while Alternative 32 only receives 0.91 value points.

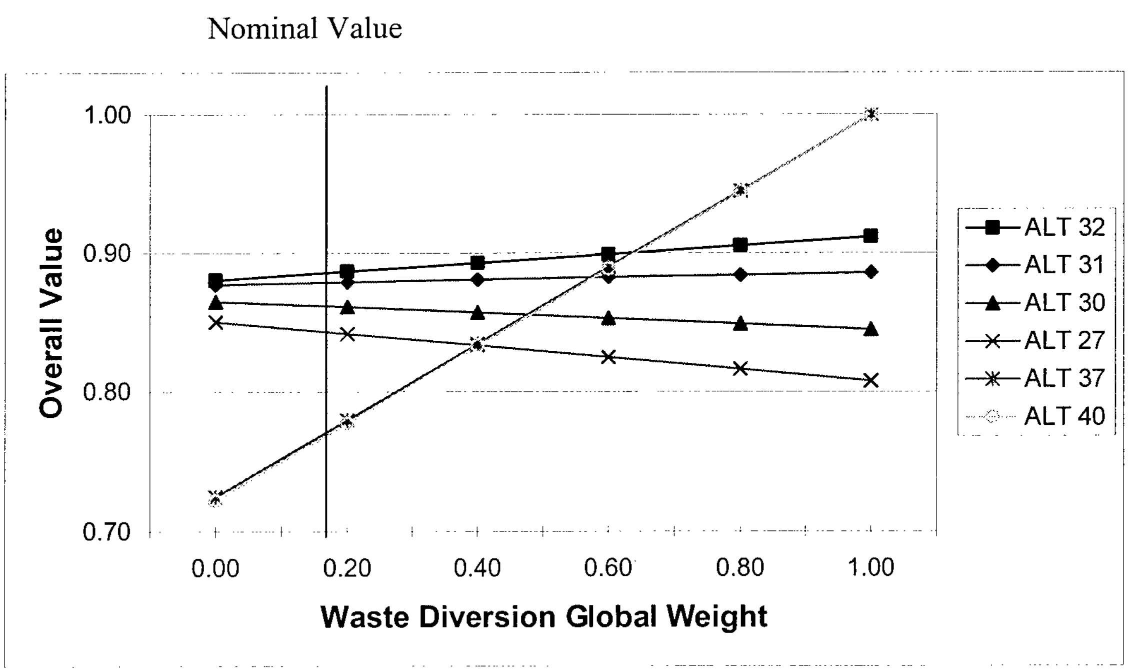


Figure 30. Sensitivity Analysis on Waste Diversion Global Weight

4.5.1.6 Implementation Time Global Weight Sensitivity. Figure 31 illustrates the sensitivity of the top ranked alternatives to implementation time as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the best alternative over the entire weight range (0 – 1.0). This makes sense because no other alternative receives more value points for this objective than Alternative 32 because this alternative has the quickest implementation time. However, there are other alternatives with an implementation time equal to Alternative 32. Thus, as implementation time weight approaches one, alternatives with an equally quickest implementation time converge.

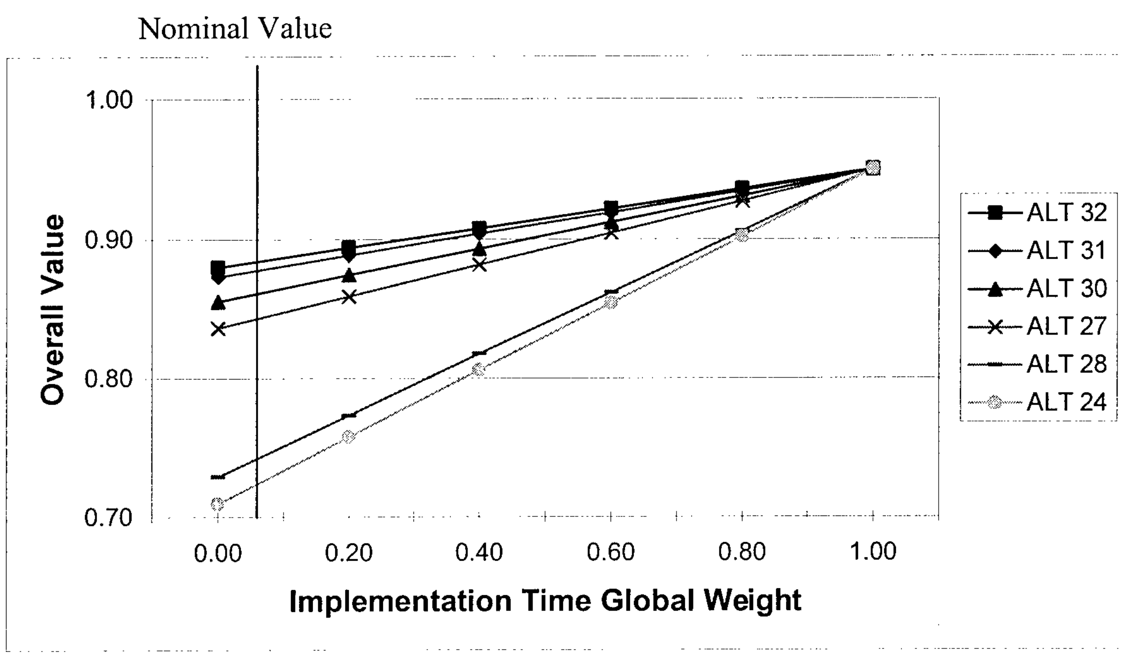


Figure 31. Sensitivity Analysis on Implementation Time Global Weight

4.5.1.7 CEV Overhead Global Weight Sensitivity. Figure 32 illustrates the sensitivity of the top ranked alternatives to overhead as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the highest ranked alternative over the range from 0 to 0.76. Alternative 17, which consists of only a Class II MSWLF, becomes the top ranked alternative when the objective weight is greater than 0.76. Alternative 17 receives more value for this objective than any other alternative because it is the only alternative that contains solely landfill operations, which requires the least amount of overhead.

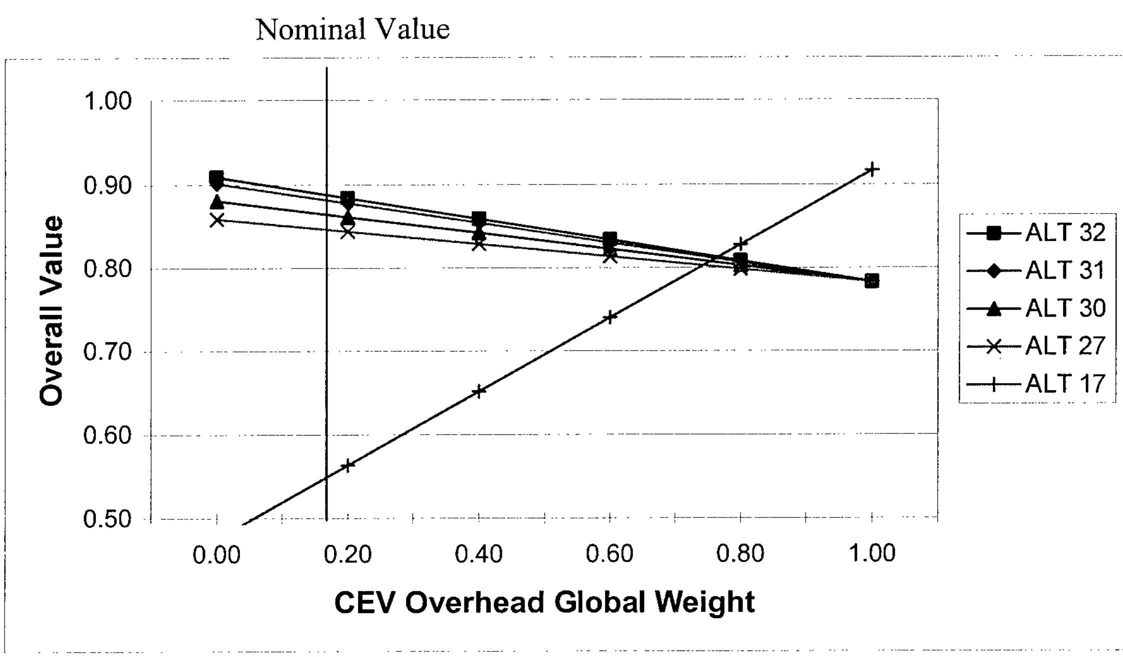


Figure 32. Sensitivity Analysis on CEV Overhead Global Weight

4.5.1.8 Liability to Air Force Global Weight Sensitivity. Figure 33 illustrates the sensitivity of the top ranked alternatives to liability as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the best alternative over the entire weight range (0 – 1.0). Alternative 32 requires only 2 permits, which the model assigns the maximum value points (1.0) possible for this objective. However, there are other alternatives with a liability equal to Alternative 32. Thus, as liability weight approaches one, alternatives with an equally lowest liability converge.

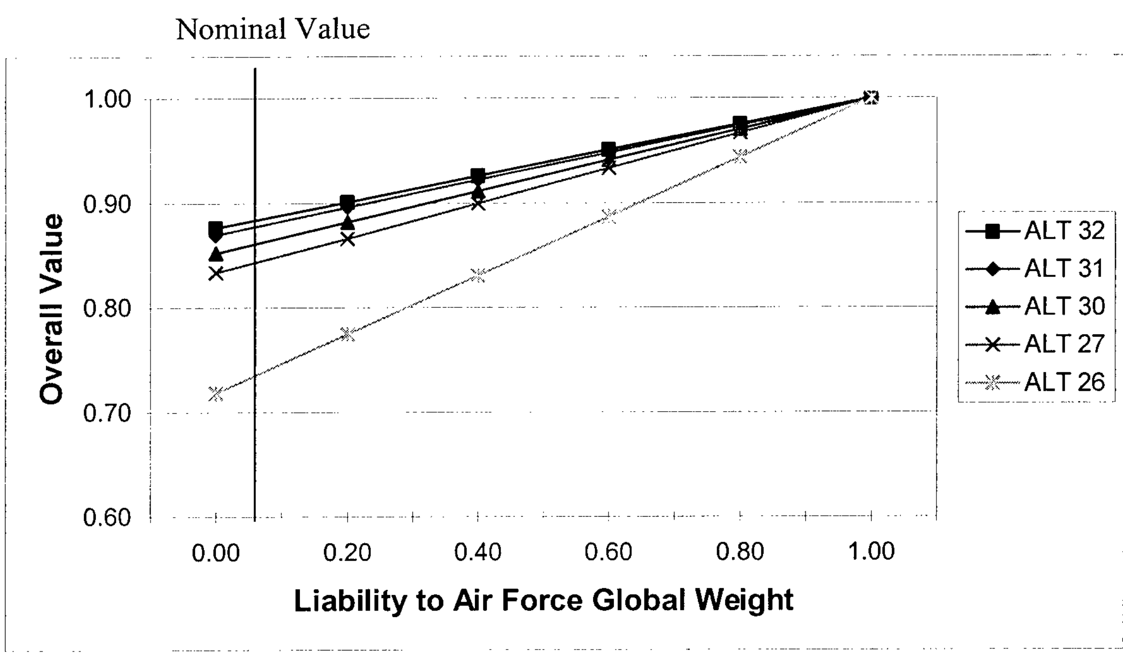


Figure 33. Sensitivity Analysis on Liability to Air Force Global Weight

4.5.1.9 Impact to Environment Global Weight Sensitivity. Figure 34 illustrates the sensitivity of the top ranked alternatives to environmental impact as the bottom-tier objective global weight is varied from 0 to 1. Alternative 32 is the best alternative over the entire weight range (0 – 1.0). In accordance with the constructed, proxy measure based on the ISWM hierarchy used to evaluate performance in this objective, the model assigns Alternative 32 the maximum possible value points (1.0) for this objective since it contains only landfill and recycling operations. However, there are other alternatives with an environmental impact equal to Alternative 32. These alternatives converge as the environment impact weight approaches one.

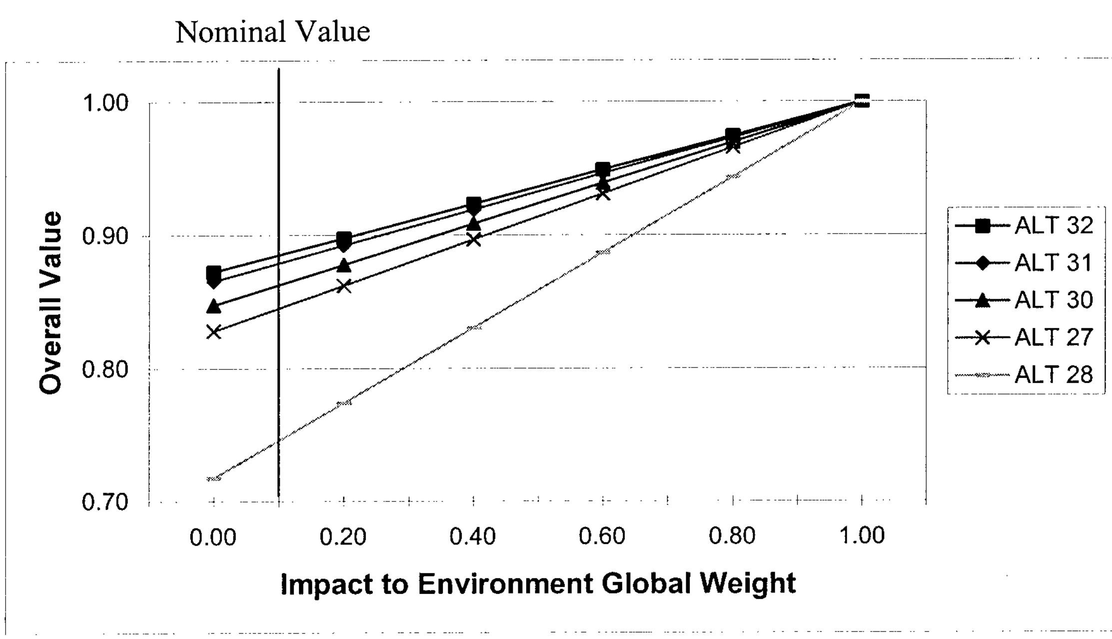


Figure 34. Sensitivity Analysis on Impact to Environment Global Weight

4.5.1.10 ***Global Weight Sensitivity Summary.*** To summarize the results of the sensitivity analyses, Table 23 indicates the impact on the highest ranked alternative (Alternative 32) as the bottom-tier objective weights are varied. Table 23 clearly shows that the highest ranked alternative is totally insensitive to four of the nine objectives (*Start-Up Cost*, *Implementation Time*, *Liability to AF*, and *Impact to Environment*). For the other five objectives, the table shows that the respective objective weight would have to significantly change before the top ranked alternative would change. Thus, it can be implied that the top ranked alternative is nearly insensitive to these five objectives as well.

Table 23. Summary of Global Weight Sensitivity Analysis on Alternative 32

Objective	Current % of Total Weight	Range Where ALT 32 is Ranked First	Alternative Replacing 32
Facility Size	0.121	0 – 0.95	4
Start-Up Cost	0.194	0 – 1.0	NA
Recurring O&M Cost	0.061	0 – 0.35	4 & 2
Facility Location	0.049	0 – 0.49	4
Waste Diversion	0.143	0 – 0.63	35, 37, & 40
Implementation Time	0.071	0 – 1.0	NA
CEV Overhead	0.194	0 – 0.76	17
Liability to AF	0.065	0 – 1.0	NA
Impact to Environment	0.097	0 – 1.0	NA

4.5.2 Local Weights Sensitivity (Third-Tier). Sensitivity analysis was performed on the local weights of the third-tier objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost*, and *Facility Location* (with respect to the second-tier objective *Resources*) and *CEV Overhead*, *Liability to Air Force*, and *Impact to Environment* (with respect to the second-tier objective *Compliance Burden*) to determine the impact on the ranking of alternatives. This type of sensitivity analysis seems more appropriate for this research effort since the local weights were the ones actually assessed from the decision-maker while the global weights were determined from the local weights and not directly assessed. Unlike global weights sensitivity analysis, local weights sensitivity analysis is performed on a group of sub-objectives with respect to the objective directly above in the objectives hierarchy. As the nominal weight of a specific third-tier objective on one branch of the hierarchy was allowed to range from 0 to 100 percent of the overall weight contribution to the objective directly above, the third-tier objectives in the other hierarchy branches remain constant. As an objective's weight is varied, only the weights of the third-tier objectives within the same branch as the objective being varied are changed proportionally to ensure the sum of the local weights remain one with respect to the objective directly above in the hierarchy.

The sensitivity analysis results indicate that the rankings of the top four model alternatives are almost totally insensitive to this weighting analysis. Only during the sensitivity analysis on the *Recurring O&M Cost* objective local weight is there a change in ranking of the top four model alternatives. For this reason, only the sensitivity graph for *Recurring O&M Cost* will be presented in this section. Appendix L contains the sensitivity analysis graphs for the remaining third-tier objectives.

Figure 35 illustrates the sensitivity of the top ranked alternatives to O&M cost as the third-tier objective local weight is varied from 0 to 1. Alternative 32 is the best alternative over the range 0 to 0.70. Alternative 30 becomes the top ranked alternative when the objective weight is greater than 0.70. The main difference between these two alternatives is that Alternative 30 has fewer recycling operations associated with it. On a cost per ton basis, O&M costs are much higher for recycling operations than landfill operations. Thus, as the importance of O&M costs increase, the overall value for both Alternatives 30 and 32 decreases. However, Alternative 30 decreases at a slower rate and is able to take over as the top ranked alternative. The top ranked alternatives remain grouped near the top because only a minimal value is assigned to them for this objective.

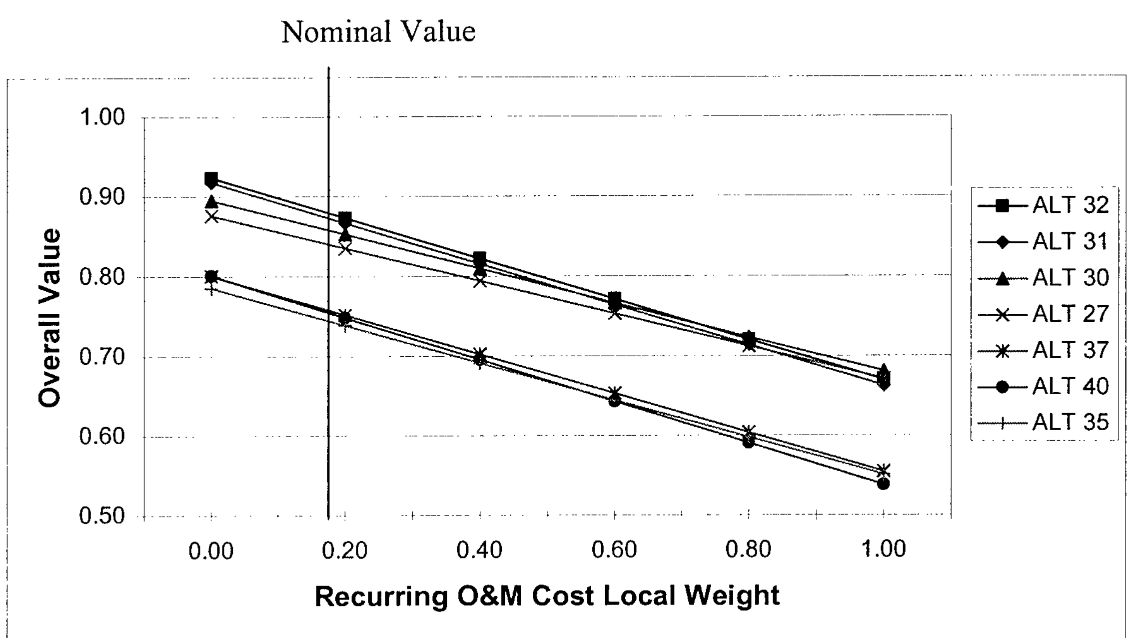


Figure 35. Sensitivity Analysis on Recurring O&M Cost Local Weight

4.5.3 Local Weights Sensitivity (Second-Tier). Sensitivity analysis was performed on the local weights of the second-tier objectives *Resources*, *Waste Diversion*, *Implementation Time*, and *Compliance Burden*. These second-tier objectives fall below the overall objective *20-Year Compliant MSW System*. As the nominal weight of a specific second-tier objective was allowed to range from 0 to 100 percent of the overall weight contribution to the overall objective directly above, the local weights of the other second-tier objectives are changed proportionally to ensure the sum of the local weights remain one with respect to the overall objective directly above in the hierarchy.

Sensitivity analysis on the local weights at this level is prudent to do because the importance of the objectives at this level could change due to a sudden change in the decision-maker's priorities. For example, implementation time is the least heavily weighted second-tier objective at this time. However, if the decision-maker receives greater pressure from regulators to get Eareckson back into compliance as soon as possible, implementation time may become much more important. The model rankings could drastically change due to the level of the hierarchy where this analysis is conducted. The resulting graphs and associated discussion follow. To make the graphs readable, only the sensitivity results of the top four model alternatives are displayed as well as those alternatives not originally ranked in the top four that become part of the top four alternatives at some point during the sensitivity range.

4.5.3.1 Resources Local Weight Sensitivity. Figure 36 illustrates the sensitivity of the top ranked alternatives to resources as the second-tier objective local weight is varied from 0 to 1. Alternative 32 is the highest ranked alternative over the range from 0 – 0.93. Alternative 4 and three other Class III MSWLF alternatives (1, 2, and 3) become the top ranked model alternatives after this point. The reason for this is that these four Class III MSWLF alternatives have the smallest landfill footprints because of the large volume reduction from incineration and recycling. In addition, these alternatives receive more value than Class II MSWLF alternatives for the objective *Landfill Location*, which is part of *Resources*. Finally, alternatives that contain incinerator operations score poorly in the other three second-tier objectives compared to those alternatives that do not have incineration operations. Thus, as these other objectives become less important, the benefits that alternatives with incineration operations receive in the *Resources* objective prevail.

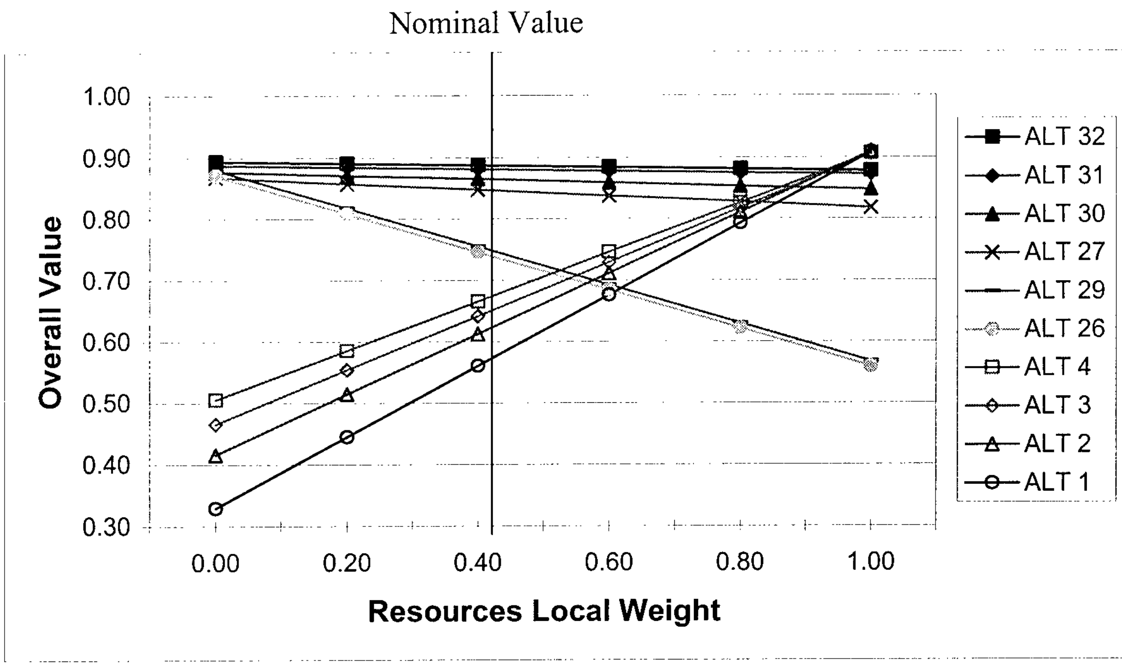


Figure 36. Sensitivity Analysis on Resources Local Weight

4.5.3.2 Waste Diversion Local Weight Sensitivity. The sensitivity analysis on the local weight for waste diversion is the same as that for the global weight for waste diversion since both of these weights are equal.

4.5.3.3 Implementation Time Local Weight Sensitivity. The sensitivity analysis on the local weight for implementation time is the same as that for the global weight for implementation time since both of these weights are equal.

4.5.3.4 Compliance Burden Local Weight Sensitivity. Figure 37 illustrates the sensitivity of the top ranked alternatives to compliance burden as the second-tier objective local weight is varied from 0 to 1. Alternative 32 is the best alternative over the entire weight range (0 – 1.0). Alternatives 32, 31, 30, and 27 all consist of landfill and recycling operations only. Alternatives with only these types of

operations receive the maximum value from two of the three sub-objectives under *Compliance Burden* and receive a considerable amount of value compared to the other alternatives for the third sub-objective. Thus, as more weight is placed on *Compliance Burden*, these objectives converge towards the same overall value score.

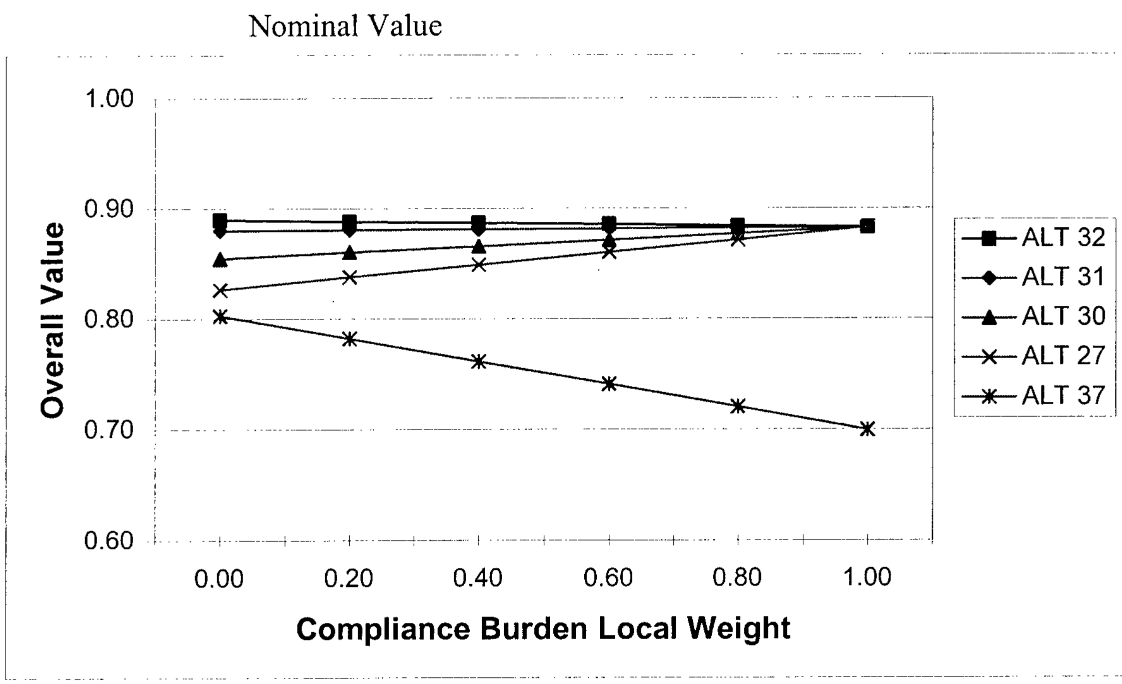


Figure 37. Sensitivity Analysis on Compliance Burden Local Weight

4.5.3.5 Local Weight Sensitivity Summary (Second-Tier). To summarize the results of the sensitivity analyses, Table 24 indicates the impact on the highest ranked alternative (Alternative 32) as the third-tier objective weights are varied. The table clearly shows that the highest ranked alternative is totally insensitive to two of the four second-tier objectives (*Implementation Time* and *Compliance Burden*). For the other two objectives, the table shows that the respective objective weight would have to significantly change before the top ranked alternative would change. Thus, it can be

implied that the top ranked alternative is nearly insensitive to these five objectives as well.

Table 24. Summary of Local Weight Sensitivity Analysis on Alternative 32

Objective	Current % of Total Weight	Range Where ALT 32 is Ranked First	Alternative Replacing 32
Resources	0.427	0 – 0.93	4
Waste Diversion	0.143	0 – 0.63	35, 37, & 40
Implementation Time	0.071	0 – 1.0	NA
Compliance Burden	0.356	0 – 1.0	NA

4.5.4 Sensitivity of Key Model Parameters. The Eareckson AS MSW decision support model is a deterministic model that determines which decision is preferred when there is no uncertainty. Point estimates (scores) for the evaluation measures for each alternative were determined and these estimates were entered into the model. In addition, point estimates were selected for some of the key model parameters. However, there is uncertainty associated with some of the evaluation measures and model parameters. For example, an 80 percent recovery rate was assumed in the model for recycling, composting, and incineration operations. What if the recovery rate were 50 percent or 90 percent? Will the highest ranked alternative change? To examine questions such as these, this section will provide the results of sensitivity analysis performed on a few key model parameters: landfill depth; recovery rate for recycling, composting, and incineration operations; and waste generation rate.

4.5.4.1 Landfill Depth Sensitivity. Since landfill depth has a direct impact on the landfill's footprint and the start-up cost, it is used in the calculations for the objective *Facility Size* and *Start-Up Cost*. A shallower landfill depth will require more

surface area (i.e., a larger footprint) to contain the waste volume. In addition, it will cost more because a landfill with a larger footprint requires more liner materials and site preparation work. The point estimate used for landfill depth in this model is 8 feet (10 feet minus 2 feet for final cover); however, landfill depth will depend on soil conditions and groundwater depth. Soil borings and other site investigation tools may be required to determine the exact design depth for the landfill. Figure 38 is a graph of the overall value assigned to the highest ranking alternatives (32, 31, 30, 27, and 37) as a function of landfill depths ranging from 6 to 12 feet (all other parameters held constant at nominal values). Two additional alternatives (28, and 29) are displayed as well since they increase in value and become one of the top five alternatives at various points. For example, alternative 28 is the sixth ranked alternative at 6 feet, but is the fifth ranked at 12 feet. As one can see from the figure, the top ranked alternative (32) does not change over the sensitivity range shown in the graph. At a landfill depth of 8 feet (the nominal value used in the model), Alternative 32 receives 0.99 out of 1.0 value points for the objective *Facility Size* and 1.0 out of 1.0 value points for the objective *Start-Up Cost*. Thus, increasing the landfill depth above 8 feet, which reduces the square footage of the facility size, can add only after 0.01 value points to Alternative 32's overall value score. Hence, the reason for the horizontal line for Alternative 32 after the vertical nominal value line. For landfill depths below 8 feet, Alternative 32 loses overall value points because it does not score as well in the *Facility Size* and *Start-Up Cost* objectives. However, it still remains the highest ranked alternative. Thus, the top ranked alternative is insensitive to landfill depth.

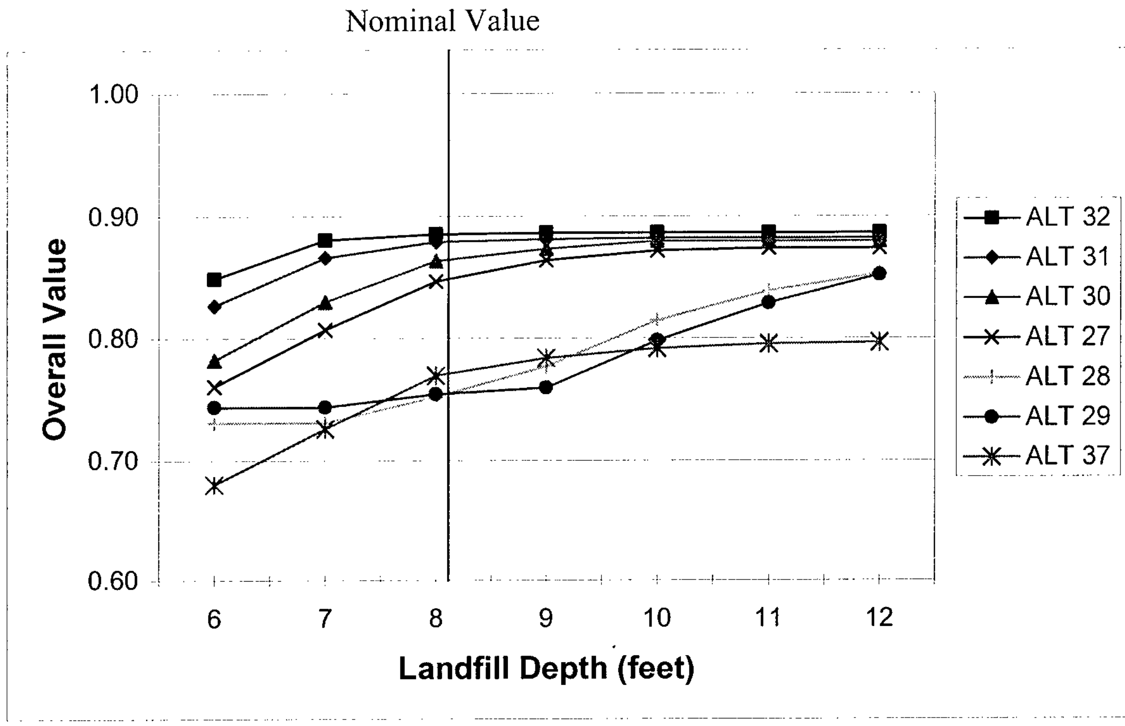


Figure 38. Sensitivity Analysis on Landfill Depth Parameter

4.5.4.2 Recovery Rate Sensitivity. The recovery rate parameter was used in the calculations for the objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost,* and *Waste Diversion*. Since these four objectives are the four most heavily weighted objectives, it is prudent to analyze the sensitivity of the decision model to this parameter. Initially, the recovery rate for materials to be recycled, composted, and/or incinerated was assumed to be 80 percent (McCloud, 2000). This is a very aggressive recovery rate when compared with EPA's national recovery goals, which vary from component to component. For example, EPA's year 2000 recovery rate goal for paper was 50 percent (Aquino, 1995:149). This was a nationwide goal though and the decision-maker believes Eareckson can achieve much higher recovery rates. Figure 39 is a graph of the overall value assigned to the highest ranking alternatives (32, 31, 30, 27, and 37) at various recovery rates ranging from 50 to 100 percent. Two additional alternatives (29 and 40)

are displayed as well since they increase in value and become one of the top five alternatives at various points. As one can see from the figure, the top ranked alternative (32) does not change over the sensitivity range shown in the graph. At a recovery rate of 80 percent (the nominal value used in the model), for the objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost,* and *Waste Diversion*, Alternative 32 receives 0.99, 1.0, 0.37, and 0.91 value points out of 1.0 for each objective, respectively. At recovery rates higher than 80 percent, Alternative 32 loses value points in the *Recurring O&M Cost* objective and gains value points in the *Facility Size* and *Waste Diversion* objectives. Overall, it receives a minimal increase in overall value points. For recovery rates ranging from 50 to 80 percent, the objectives *Facility Size* and *Waste Diversion* account for the majority of the value loss among the four objectives above. Overall, though, Alternative 32 still remains the highest ranked alternative. Thus, the top ranked alternative is insensitive to recovery rate over the range shown in the graph.

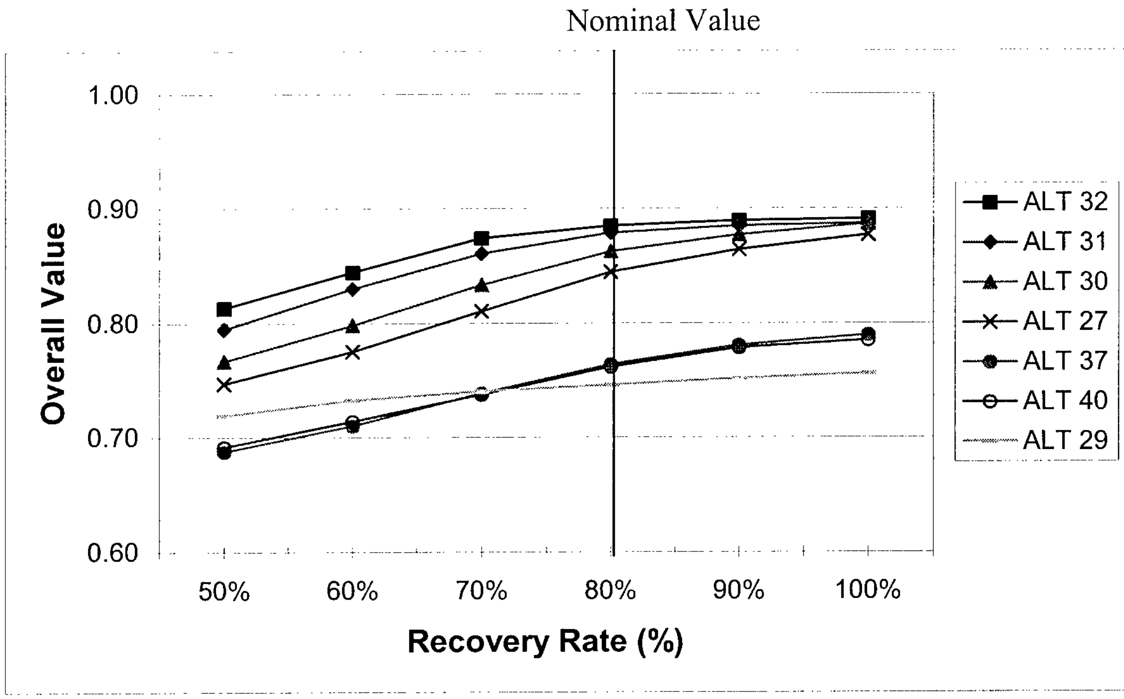


Figure 39. Sensitivity Analysis to Recovery Rate

4.5.4.3 Waste Generation Rate Sensitivity. Perhaps the most important parameters in the model are the Eareckson AS waste stream characterization data. These parameters were used in the calculations for the objectives *Facility Size*, *Start-Up Cost*, *Recurring O&M Cost,* and *Waste Diversion.* As discussed in Chapter 2, reliable data on the quantity and composition of the MSW stream to be managed is required to properly analyze the available waste management techniques and technologies. (Appendix D provides the procedure used to collect the data used in the model.) The sensitivity analysis in Figure 40 shows the effects on overall value of the highest ranking alternatives (32, 31, 30, 27, and 37) by varying the estimated annual waste generated (weight in pounds) for each MSW component in the model from 50 percent below to 50 percent above each component's nominal value. Two additional alternatives (29 and 40) are displayed as well since they increase in value and become one of the top five

alternatives at various points. As one can see from the figure, the top ranked alternative (32) does not change over the sensitivity range shown in the graph. For the objectives *Facility Size, Start-Up Cost, Recurring O&M Cost,* and *Waste Diversion*, Alternative 32 receives 0.99, 1.0, 0.37, and 0.91 value points out of 1.0 for each objective, respectively, when using the Eareckson AS waste characterization data found at the end of Appendix D. As the annual waste generated by MSW component decreases from the components' nominal values (left of the nominal values line in the figure), the overall value of each alternative slightly increases over the range in the graph. This increase is mainly the result of the objective *Recurring O&M Cost* gaining value as less waste has to be handled and disposed of. The figure also shows several alternatives beginning to converge at minus 50 percent on the graph. This behavior is mostly attributed to the fact that all of the alternatives score the maximum value points possible for *Facility Size* and *Start-Up Cost* at this point and score exactly the same on all other objectives except *Recurring O&M Cost* and *Waste Diversion.* The difference in scores for these later two objectives is minimal though. As the annual waste generated by MSW component increases from the components' nominal values (right of the nominal values line in the figure), the overall value of each alternative decreases. This is because more waste has to be handled and disposed of, which increases the required landfill size and operational costs. As a result, the objectives *Facility Size, Start-Up Cost,* and *Recurring O&M Cost* decrease in value over this range in the graph. Overall, Alternative 32 remains the highest ranked alternative throughout the range in Figure 40. Thus, it is insensitive to changes in the waste characterization data's annual waste generated over the range shown in the graph.

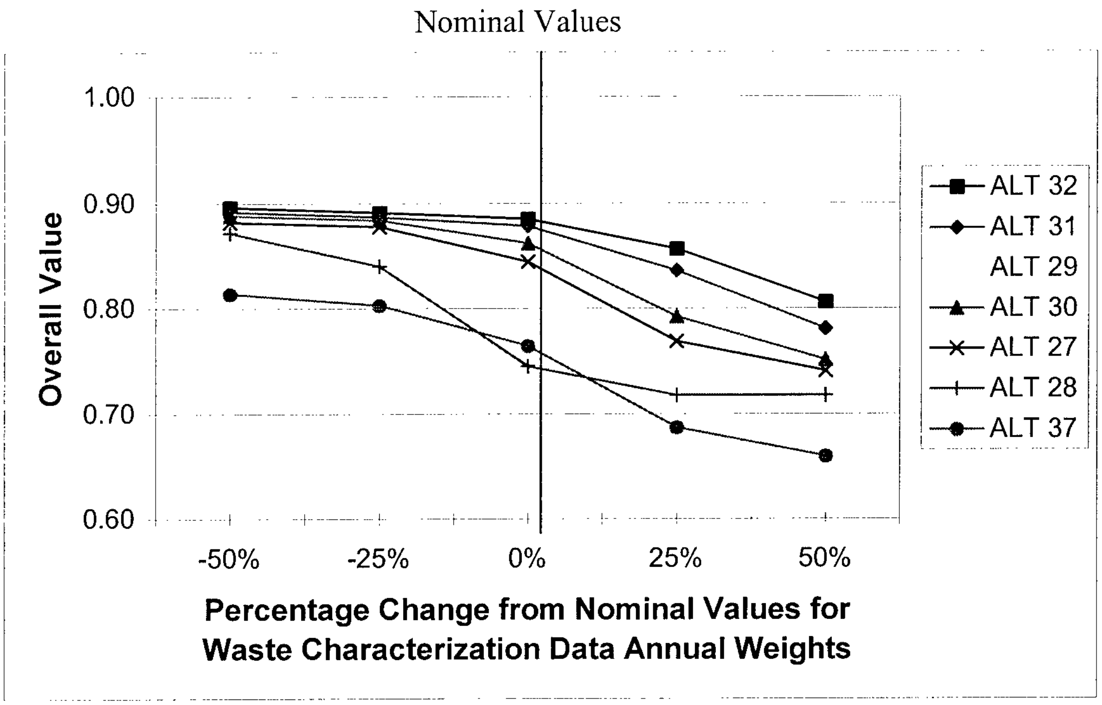


Figure 40. Sensitivity Analysis to Waste Characterization Data Annual Weights

Chapter 5. Findings and Conclusions

5.1 Overview

This research provides a deterministic decision analysis model to aid the decision-maker at Eareckson Air Station (AS) in choosing a municipal solid waste (MSW) management strategy that best meets his MSW objectives. Value-focused thinking techniques helped create the decision-maker's fundamental objectives hierarchy. The hierarchy consists of a single overall (top-tier) objective and four second-tier fundamental objectives that are decomposed further into nine bottom-tier objectives. Each bottom-tier objective is quantified into a set of nine measures. Finally, multiattribute preference theory techniques were used to determine weights associated with each second-tier and bottom-tier objective and convert evaluation measure scores into value units based on the decision-maker's preferences.

The decision analysis model uses the decision-maker's weights and value functions to convert a MSW alternative's performance in the nine measures into component values for each of the nine bottom-level fundamental objectives. Then an additive value function combines the component values of the nine bottom-tier objectives to determine each alternative's ability to meet the decision-maker's overall objective, a 20-year compliant MSW strategy.

The decision analysis model provides helpful visual aids that present each alternative's overall value and the contributing value of each of the bottom-tier objectives. In addition, the model can perform sensitivity analysis on not only the weights associated with each objective, but also some of the key model parameters. The

weight sensitivity analysis shows the insensitivity of the top-ranked MSW alternative to changes in the objective weights. The key model parameters sensitivity analysis shows which parameters, when varied from their nominal values, are most influential in changing the top-ranked alternative; indicating which parameters may need more accurate estimates or detailed modeling to account for uncertainty.

5.2 Answer to Research Question

A total of 40 different MSW alternatives, developed in accordance with the decision-maker's assumptions and constraints, were evaluated with the multiple-objective decision analysis model. Based on overall value to the decision-maker, the model results suggest that the Eareckson AS MSW strategy should be a Class II municipal solid waste landfill (MSWLF) along with a recycling combination that includes at least paper and cardboard recycling. The top four alternatives (32, 31, 30, and 27) all contain a Class II MSWLF, recycling of paper and cardboard, and no incineration or composting.

The top-ranked alternative consists of a Class II MSWLF along with the recycling of aluminum cans, steel cans, glass, paper, and cardboard. Sensitivity analysis shows that the top-ranked alternative (Alternative 32) is insensitive to moderate changes in the model objective weights and key model parameters, which strengthens the argument for the implementation of this alternative. This alternative has several advantages to it. First, it has the least expensive start-up cost of the 40 alternatives evaluated. Second, it has the potential of diverting up to 32 percent of the waste stream. Third, it has a footprint that is nearly half the size of the footprint estimated by Jacobs (2000). Fourth, it

has one of the quickest implementation times. Finally, it poses minimal liability to the Air Force and minimal impact to the environment as defined by the decision-maker.

There are several reasons why alternatives that consist of a Class II MSWLF and the recycling of paper and cardboard came out on top. First, paper and cardboard account for nearly 26 percent of the Eareckson AS waste stream by weight. Recycling these items scores high on the decision-maker's *Waste Diversion* objective (before weighting). Incinerating paper and cardboard, however, does not receive any value points for this objective because incineration is not considered waste diversion. Since alternatives with a Class III MSWLF must include an incinerator, combined with the decision-maker's constraint that all combustibles will be combusted if an incinerator is part of the alternative, alternatives with a Class III MSWLF receive minimal value points for the *Waste Diversion* objective. Second, paper and cardboard account for nearly 54 percent of the Eareckson AS waste stream by volume. By diverting such a large percentage of the waste stream away from landfill disposal, a much smaller landfill footprint is required. The smaller the landfill footprint, the more value an alternative receives for the *Facility Size* objective. In addition, the smaller the landfill footprint, the less expensive the start-up cost is for the landfill portion of the total start-up cost. Since the savings associated with building a smaller landfill facility due to recycling paper and cardboard far outweighs the cost of implementing a paper and cardboard recycling program, alternatives with a Class II MSWLF and no incinerator or composting receive nearly all of the value points for the *Start-Up Cost* objective. On the other hand, alternatives with a Class III landfill receive far less value for this objective in spite of a reduced facility size because of the additional cost of an incinerator facility.

If the decision-maker decides to use an alternative with composting, this analysis indicates that Alternative 37, which is the fifth ranked alternative based on overall value, should be selected. This alternative has the potential of diverting nearly 56 percent of the waste stream by weight (mostly food waste) and is the highest scoring alternative for the *Waste Diversion* objective. However, the top-ranked alternative scores better or equal to Alternative 37 in the other eight bottom-tier model objectives. Furthermore, if the decision-maker decides to use an incinerator alternative, this analysis indicates that Alternative 4 should be selected. In addition to an incinerator, Alternative 4 includes a Class III MSWLF and the recycling of aluminum cans, steel cans, and glass. This alternative, however, is ranked 22nd of 40 and its overall value is more than 0.22 value points less than the top-ranked alternative.

5.3 Model Strengths

This research effort represents the first publicly documented use of value-focused thinking and multiattribute preference theory techniques to produce a multiple-objective MSW decision analysis model. Klee (1980: Ch 3) discusses the use of multiattribute decision-making techniques in resource recovery activities; however, he does not use it, nor does he refer to any case studies or works that use it. If the technique has been applied elsewhere, that application is not published to the knowledge of the author.

The spreadsheet model developed in this research has several strong points. The primary strength is the model's flexibility. Model parameters, such as the waste stream characterization data, can easily be updated to reflect the most current available data. A second model strength is its ability to provide valuable insight towards those objectives

and parameters that have the largest influence on the final result. This allows the decision-maker to make a better informed and defensible decision. Another strength of the model is its reliance on popular spreadsheet software. Most managers are generally familiar with this tool and are more likely to trust the results than if they came from an unfamiliar software program. Managers can even do the modeling themselves rather than relying on an analyst or consultant.

5.4 Model Weaknesses

The model also has several weaknesses. One weakness is it is a deterministic model that assumes there is no uncertainty with alternative evaluation measure scores and model parameters. Point estimates based on expert opinion and the solid waste literature were used for the evaluation measure scores and model parameters. However, there is uncertainty with many of these measures and parameters. These uncertainties may influence the alternative rankings obtained from the model and possibly change the top-ranked decision. Sensitivity analysis was used in an attempt to consider the effects of some of the uncertainties.

Another weakness is that the model only has limited application because of its inability to be easily adapted to other similar multiple-objective MSW decision problems in which the decision-maker has objectives that differ from the ones used in this model. However, the methodology used in this research to develop the Eareckson MSW model is extremely flexible and could be used to develop a new model.

5.5 Recommendations for Future Work

This thesis was limited in scope to MSW management handling techniques (landfilling, incineration, composting, and recycling) available to Eareckson AS to manage waste after it is generated. Source reduction opportunities could be evaluated and the effect of these opportunities on the future waste stream could be incorporated into the model. In addition, probabilistic techniques could be incorporated into the model to better account for the uncertainty involved with many of the model parameters and measures. This would give the decision-maker more insight into the range and distribution of the overall value for each alternative and its likelihood. Furthermore, an additional waste stream characterization study could be conducted at Eareckson and incorporated into the study conducted in this research effort to better define the quantity and composition of Eareckson's waste stream. The waste stream characterization data is crucial to several of the measures in this model. Finally, perhaps some additional or better measures could be incorporated into the model. For example, the objective *Impact to Environment* in this model uses a constructed, proxy scale based on EPA's integrated solid waste management hierarchy to measure this objective. Perhaps total emissions (solid waste, air, and wastewater) is a better measure.

Appendix A: Decision-Making Team

The purpose of this appendix is to identify the key personnel for this decision analysis effort. They are as follows:

Individual	Role
Maj Kent Nonaka Commander, 611 CES Environmental Flight	Decision-Maker
Capt Mark J. Shoviak Graduate Student	Decision Analyst
Capt Mark McCloud Chief, Environmental Compliance	Team Member
Capt Scott Barrion Pollution Prevention Program Manager	Team Member
Mr. James Fife Solid Waste Program Manager	Team Member
Mr. Craig Valentine Eareckson AS Environmental Engineer	Team Member
Mr. Deven Dalcher Air Program Manager	Team Member

Appendix B: Weight Calculations

The purpose of this appendix is to provide the calculations used to determine the global and local weights for the objectives hierarchy. These weights are then used in the model.

Key :
LW = Local Weight
GW = Global Weight

Local Weights for Resource Sub-Objectives

$LW_{\text{Start-Up Cost}} = 4 * LW_{\text{Facility Location}}$
$LW_{\text{Facility Size}} = 2.5 * LW_{\text{Facility Location}}$
$LW_{\text{Recurring O\&M Cost}} = 1.25 * LW_{\text{Facility Location}}$

$LW_{\text{Start-Up Cost}} + LW_{\text{Facility Size}} + LW_{\text{Recurring O\&M Cost}} + LW_{\text{Facility Location}} = 1$
$(4 + 2.5 + 1.25 + 1)\ LW_{\text{Facility Location}} = 1$
$LW_{\text{Facility Location}} = 0.114$

Therefore,

$LW_{\text{Start-Up Cost}} = 4* LW_{\text{Facility Location}} = 4 * 0.114 = 0.456$
$LW_{\text{Facility Size}} = 1.25* LW_{\text{Facility Location}} = 2.5 * 0.114 = 0.285$
$LW_{\text{Recurring O\&M Cost}} = 2.5* LW_{\text{Facility Location}} = 1.25 * 0.114 = 0.143$

Local Weights for Compliance Burden Sub-Objectives

$LW_{\text{Impact to Environment}} = 1.5 * LW_{\text{Liability to AF}}$
$LW_{\text{CEV Overhead}} = 3 * LW_{\text{Liability to AF}}$

$LW_{\text{Impact to Environment}} + LW_{\text{CEV Overhead}} + LW_{\text{Liability to AF}} = 1$
$(1.5 + 3 + 1)\ LW_{\text{Liability to AF}} = 1$
$LW_{\text{Liability to AF}} = 0.182$

Therefore,

$LW_{\text{Impact to Environment}} = 1.5 * LW_{\text{Liability to AF}} = 1.5 * 0.182 = 0.273$
$LW_{\text{CEV Overhead}} = 3 * LW_{\text{Liability to AF}} = 3 * 0.182 = 0.546$

Local Weights for 20-Year Compliant MSW System Sub-Objectives

$LW_{\text{Resources}} = 6 * LW_{\text{Implementation Time}}$
$LW_{\text{Compliance Burden}} = 5 * LW_{\text{Implementation Time}}$
$LW_{\text{Waste Diversion}} = 2 * LW_{\text{Implementation Time}}$

$LW_{\text{Resources}} + LW_{\text{Compliance Burden}} + LW_{\text{Waste Diversion}} + LW_{\text{Implementation Time}} = 1$
$(6 + 5 + 2 + 1)\, LW_{\text{Implementation Time}} = 1$
$LW_{\text{Implementation Time}} = 0.071$

Therefore,

$LW_{\text{Resources}} = 6 * LW_{\text{Implementation Time}} = 6 * 0.071 = 0.426$
$LW_{\text{Compliance Burden}} = 5 * LW_{\text{Implementation Time}} = 5 * 0.071 = 0.355$
$LW_{\text{Waste Diversion}} = 2 * LW_{\text{Implementation Time}} = 2 * 0.071 = 0.142$

Global Weights for Last-Tier Objectives

$GW_{\text{Start-Up Cost}} = LW_{\text{Resources}} * LW_{\text{Start-Up Cost}} = 0.426 * 0.456 = 0.194$
$GW_{\text{Facility Size}} = LW_{\text{Resources}} * LW_{\text{Facility Size}} = 0.426 * 0.285 = 0.121$
$GW_{\text{Recurring O\&M Cost}} = LW_{\text{Resources}} * LW_{\text{Recurring O\&M Cost}} = 0.426 * 0.143 = 0.061$
$GW_{\text{Facility Location}} = LW_{\text{Resources}} * LW_{\text{Facility Location}} = 0.426 * 0.114 = 0.0486$

$GW_{\text{Implementation Time}} = LW_{\text{Implementation Time}} = 0.071$
$GW_{\text{Waste Diversion}} = LW_{\text{Waste Diversion}} = 0.142$

$GW_{\text{CEV Overhead}} = LW_{\text{Compliance Burden}} * LW_{\text{CEV Overhead}} = 0.355 * 0.546 = 0.194$
$GW_{\text{Impact to Environment}} = LW_{\text{Compliance Burden}} * LW_{\text{Impact to Environment}} = 0.355 * 0.273 = 0.097$
$GW_{\text{Liability to AF}} = LW_{\text{Compliance Burden}} * LW_{\text{Liability to AF}} = 0.355 * 0.182 = 0.065$

Appendix C: Eareckson Air Station Decision Support Model Alternatives

The purpose of the spreadsheet contained in this appendix is to provide a list of the 40 municipal solid waste (MSW) alternatives evaluated by this research. The ones and zeros in the table act as binary switches for calculations throughout the model that reference this appendix.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Appendix C: Eareckson Air Station Decision Support Model Alternatives**											
2												
3	**Key:**	C3C	=	Class III MSWLF at Current Location								
4		C2AN	=	Class II MSWLF at Location A								
5		IM	=	Modular Incinerator								
6		IN	=	No Incinerator								
7		RA	=	Recycle Aluminum & Tin Cans								
8		RG	=	Recycle Glass								
9		RP	=	Recycle Paper								
10		RC	=	Recycle Cardboard								
11		RN	=	No Recycling								
12		CI	=	In-Vessel Composting								
13		CN	=	No Composting								
14		1	=	MSW management technique(s) included in the alternative								
15	**Alternative**	**C3C**	**C2AN**	**IM**	**IN**	**RA**	**RG**	**RP**	**RC**	**RN**	**CI**	**CN**
16	1	1	0	1	0	0	0	0	0	1	0	1
17	2	1	0	1	0	1	0	0	0	0	0	1
18	3	1	0	1	0	0	1	0	0	0	0	1
19	4	1	0	1	0	1	1	0	0	0	0	1
20	5	1	0	1	0	0	0	0	0	1	1	0
21	6	1	0	1	0	1	0	0	0	0	1	0
22	7	1	0	1	0	0	1	0	0	0	1	0
23	8	1	0	1	0	1	1	0	0	0	1	0
24	9	0	1	1	0	0	0	0	0	1	0	1
25	10	0	1	1	0	1	0	0	0	0	0	1
26	11	0	1	1	0	0	1	0	0	0	0	1
27	12	0	1	1	0	1	1	0	0	0	0	1
28	13	0	1	1	0	0	0	0	0	1	1	0
29	14	0	1	1	0	1	0	0	0	0	1	0
30	15	0	1	1	0	0	1	0	0	0	1	0
31	16	0	1	1	0	1	1	0	0	0	1	0
32	17	0	1	0	1	0	0	0	0	1	0	1
33	18	0	1	0	1	1	0	0	0	0	0	1

	A	B	C	D	E	F	G	H	I	J	K	L
15	**Alternative**	**C3C**	**C2AN**	**IM**	**IN**	**RA**	**RG**	**RP**	**RC**	**RN**	**CI**	**CN**
34	19	0	1	0	1	0	1	0	0	0	0	1
35	20	0	1	0	1	0	0	1	0	0	0	1
36	21	0	1	0	1	0	0	0	1	0	0	1
37	22	0	1	0	1	1	1	0	0	0	0	1
38	23	0	1	0	1	1	0	1	0	0	0	1
39	24	0	1	0	1	1	0	0	1	0	0	1
40	25	0	1	0	1	0	1	1	0	0	0	1
41	26	0	1	0	1	0	1	0	1	0	0	1
42	27	0	1	0	1	0	0	1	1	0	0	1
43	28	0	1	0	1	1	1	1	0	0	0	1
44	29	0	1	0	1	1	1	0	1	0	0	1
45	30	0	1	0	1	1	0	1	1	0	0	1
46	31	0	1	0	1	0	1	1	1	0	0	1
47	32	0	1	0	1	1	1	1	1	0	0	1
48	33	0	1	0	1	0	0	0	0	1	1	0
49	34	0	1	0	1	1	0	0	0	0	1	0
50	35	0	1	0	1	0	1	0	0	0	1	0
51	36	0	1	0	1	0	0	0	1	0	1	0
52	37	0	1	0	1	1	1	0	0	0	1	0
53	38	0	1	0	1	1	0	0	1	0	1	0
54	39	0	1	0	1	0	1	0	1	0	1	0
55	40	0	1	0	1	1	1	0	1	0	1	0

Appendix D: Waste Stream Characterization Plan and Data

According to Tchobanoglous *et al.* (1993: 17), the development of an effective ISWM system depends on the availability of reliable data regarding the characteristics of the waste stream. Reliable data is important because the quantity and composition of the solid waste stream has a direct impact on the techniques and technologies selected for management and disposal. Without a good idea of the quantities that can be expected, decisions about equipment and space needs, facilities, markets, and personnel cannot be reliably made (USEPA, 1995: 3-4). Furthermore, the composition of the solid waste stream is important for assessing potential environmental impacts associated with the different disposal options (Lund, 1993: 3.2). For example, for landfill disposal, the composition of the MSW to be buried has an impact on the assumed in-place density, which in turn affects landfill capacity and landfill life expectancy.

The last waste characterization study conducted at Eareckson AS was completed in 1992 when some 700 military and contractor personnel resided at Eareckson AS (Jacobs, 1995). Table 25 provides the results of this study. In 1994, operations at the installation were significantly reduced and daily operations and maintenance activities were transferred to a base operations support (BOS) contract. The current yearly population now averages around 116 people (PACAF, 2000). Because of these significant changes, the results of the 1992 study are no longer valid. Thus, another solid waste characterization study needs to be conducted to establish reliable waste composition data.

Table 25. 1992 Eareckson AS MSW Characterization Study

Component	1992 Baseline Weight (lb)	Component % by Weight
Paper Products:		
Computer	202,014	10.6
High Grade Office	258,755	13.6
Cardboard	289,027	15.2
Newspaper	64,736	3.4
Magazines	49,123	2.6
Mixed	90,630	4.8
Sub Total:	**954,285**	**50.1**
Food Waste:	**167,742**	**8.8**
Containers:		
Glass	116,144	6.1
Aluminum	36,938	1.9
Bi-metal/Tin	70,638	3.7
Plastic PET (1)	8,949	0.5
Plastic HDPE (2)	37,890	2.0
Sub Total:	**270,558**	**14.2**
Plastic:		
PVC (3)	1,200	0.1
LDPE (4)	26,085	1.4
PS (6)	8,758	0.5
Other	106,896	5.6
Sub Total:	**142,939**	**7.5**
Metals:		
Ferrous	84,347	4.4
Aluminum	2,285	0.1
Brass	1,142	0.1
Copper	1,714	0.1
Other	190	0.0
Sub Total:	**89,678**	**4.7**
Wood:	**15,499**	**0.8**
Tires:	**21,706**	**1.1**
Batteries:		

Lead Acid	190	0.0
Dry Cell	1,363	0.1
Sub Total:	**1,553**	**0.1**
Miscellaneous:		
Household Hazardous Waste	9,901	0.5
Construction Debris	195,350	10.3
Textiles	16,946	0.9
Rubber	6,854	0.4
Leather	2,285	0.1
Other	8,758	0.5
Sub Total:	**240,094**	**12.6**
Total:	**1,904,054**	**100.0**

(Jacobs, 1995)

Hickman identifies three key aspects in conducting a waste characterization study (1999: 60): (1) determining the generators or sources, (2) defining or profiling characteristics of each generator, and (3) characterizing the solid waste streams from each generator or source. For the case of Eareckson AS, the installation is the only waste generator on the island. As a government facility, Eareckson AS is best profiled as an institutional waste source (Tchobanoglous *et al.*, 1993: 41).

Before conducting a waste characterization study, the numerous component categories the waste will be divided up into should be determined. It is important to take into account as many component categories as can be foreseen at the time of study execution in order to avoid the need to conduct another study should market or regulatory requirements change (Stessel, 1996: 27). With this advice in mind, the waste composition data sheet at Figure 41 was developed and employed in recording waste composition data during the solid waste characterization study at Eareckson AS.

Waste Compostion Data Sheet Date: ___________ Site: ____________ Sample #: _______				
	Weight in Pounds			% of
Component	Gross	Tare		Total
Paper Products:				
High Grade Office				
Corrugated				
Newsprint				
Magazines				
Mixed Paper				
Food Waste:				
Containers:				
Glass				
Aluminum				
Bi-metal/Steel				
Plastic PETE (1)				
Plastic HDPE (2)				
Plastics:				
PVC (3)				
LDPE (4)				
PP (5)				
PS (6)				
Other				
Metals:				
Ferrous				
Aluminum				
Brass				
Copper				
Other				
Wood:				
Miscellaneous:				
Textiles				
Rubber				
Leather				
Other				
Totals:				

Figure 41. Waste Composition Data Sheet

To characterize the composition of the solid waste stream at Eareckson AS, ASTM Standard D5231-92, "Standard Test for Determination of the Composition of Unprocessed Municipal Solid Waste," was employed. According to the standard, "this test method applies to determination of the mean composition of MSW based on the collection and manual sorting of a number of samples of waste over a selected time period covering a minimum of one week" (ASTM, 1992: 1). The process behind the ASTM standard can be summarized in four main steps: (1) calculate the number of samples to be collected and sorted based on statistical criteria selected by the investigator, (2) randomly select vehicle loads for sampling and collect a sorting sample from the discharged vehicle load, (3) manually sort the waste into components and calculate the weight fraction of each component, and (4) calculate the mean waste composition using the composition of each of the sorting samples.

The number of sorting samples (n) required to achieve a desired level of measurement precision is a function of the components under investigation and the statistical confidence level (ASTM, 1992: 4). The equation for n is as follows:

$$n = (t^* \cdot s / e \cdot \bar{x})^2 \qquad \text{D.1}$$

where:

t^* = student t statistic corresponding to the desired level of confidence,

s = estimated standard deviation,

e = desired level of precision, and

$\bar{x}$ = estimated mean.

Values for t^* at the 90% and 95% confidence levels and suggested values for s and $\bar{x}$ can be found in the ASTM standard. The precision value (e) is a percentage value determined by the investigator.

Using the procedure outlined by ASTM, the required sample size (n) for the solid waste study at Eareckson AS was calculated to be 52 samples. The following assumptions were made for the sample size calculation: corrugated is selected as the governing component, a 90% confidence level is desired, and a 10% precision level is desired.

With the required sample size for the Eareckson AS study calculated, the procedures used for randomly selecting loads and collecting samples will now be discussed. ASTM recommends samples be collected from randomly selected vehicle loads of waste and that sample sizes be between 200 to 300 pounds (1992: 1). Because of the very small size of the MSW system at Eareckson and the fact waste is only collected twice a week from 20 dumpsters, it is not possible to randomly sample 52 vehicle loads during the course of a one-week study. Instead, trash dumpsters were substituted for vehicles and randomly selected using a random number generator. The complete contents of a randomly selected dumpster was emptied into a waste collection vehicle and taken to a sorting station located in a vacant hangar. Here, the collected waste sample was sorted into the component categories found in Figure 41 and each component weighed. The mass fraction of each component was then calculated for each dumpster.

At the end of the study, a total of 66 samples were collected, sorted, and weighed. The final results of this study may be found at the end of this chapter. The mean component composition was calculated using the component composition results from each of the analysis samples. The mean mass fraction of component i, $\overline{mf_i}$, was calculated as follows:

$$\overline{mf_i} = \frac{1}{n}\sum_{k=1}^{n}(mf_i)_k \qquad \text{D.2}$$

where:

n = number of samples

mf_i = mass fraction of component i

While this process characterizes the solid waste stream during a one-week period, consideration must be given to seasonal changes in the waste stream. Most authors and publications recommend performing four separate week-long waste characterization studies (winter, spring, summer, fall) at each site to account for seasonal variability of the waste stream (Lund, 1993: 3.19; Hickman, 1999: 58, USEPA, 1995: 3-8). Although a four-week program is the most preferable approach, it is usually possible to assess significant seasonal variations by conducting the solid waste characterization study in only two of the four seasons (Lund, 1993: 3-19).

Because of time limitations for this thesis effort, only one study event was conducted. However, Eareckson AS solid waste management personnel were interviewed to gauge the seasonal variability of the waste stream. According to the site environmental program manager, the only seasonal variability the site experiences is an increase in personnel during the short summer construction season in June, July, and August (Castle, 2000). The size of this population increase varies from year to year depending on the number of construction projects at the site (McCloud, 2000).

	A	B	C	D	E
1	**Eareckson Air Station MSW Stream Characterization Data**				
2					
3			**Weight in Pounds (lbs)**		
4		**Study**	**Daily**	**Annual**	**% by**
5	**Component**	**Total**	**Average**	**Estimate**	**Weight**
6	**Paper Products:**				
7	High Grade Office	19.2	6.4	2,336	0.9%
8	Corrugated	397.0	132.3	48,302	17.8%
9	Newsprint	1.5	0.5	183	0.1%
10	Magazines	43.6	14.5	5,305	2.0%
11	Mixed Paper	161.0	53.7	19,588	7.2%
12	**Food Waste:**	1,067.8	355.9	129,916	47.9%
13	**Containers:**		0.0	0	0.0%
14	Glass	217.6	72.5	26,475	9.8%
15	Aluminum	36.5	12.2	4,441	1.6%
16	Bi-metal/Steel	67.5	22.5	8,213	3.0%
17	Plastic PETE (1)	18.0	6.0	2,190	0.8%
18	Plastic HDPE (2)	7.8	2.6	949	0.4%
19	**Other Plastics:**	73.3	24.4	8,918	3.3%
20	**Metals:**		0.0	0	0.0%
21	Ferrous	5.5	1.8	669	0.2%
22	Nonferrous	14.0	4.7	1,703	0.6%
23	Other	23.0	7.7	2,798	1.0%
24	**Wood:**	17.5	5.8	2,129	0.8%
25	**Miscellaneous:**		0.0	0	0.0%
26	Textiles	17.8	5.9	2,166	0.8%
27	Rubber	11.7	3.9	1,424	0.5%
28	Leather	1.8	0.6	219	0.1%
29	Dirt, ashes, etc.	25.3	8.4	3,078	1.1%
30	**Totals:**	2,227	742	271,000	100.0%

Appendix E: Data for Facility Size Objective

This appendix contains the spreadsheet model used to calculate the facility size for each alternative in Appendix C. First, volume and waste estimates are calculated for each MSW component based on the Eareckson Air Station (AS) waste stream characterization data presented at the end of Appendix D. Then the volume of waste to be handled by the different municipal solid waste (MSW) management techniques for each alternative is calculated. Finally, the estimated landfill footprint for each alternative is calculated.

	A	B	C	D	E	F	G
1			**Appendix E: Data for Facility Size Objective**				
2							
3	**Data for Model Assumptions**						
4	Landfill Depth (ft)	8	(effective depth is 8 ft because the final cover will take-up 2 ft) (Jacobs, 2000)				
5	Final Cover (ft)	2	(ADEC, 1999)				
6	Waste-to-Soil	2					
7	Recovery Factor	80%					
8	Population Growth	2					
9							
10	**Calculations for MSW Volume & Weight Estimates**						
11							
12			**Uncompacted**	**% of**	**Compacted**	**Volume**	**Weight**
13		**Annual**	**Annual**	**Waste Stream**	**Volume in**	**After**	**After**
14		**Estimated**	**Estimated**	**by Volume**	**Landfill[c]**	**Incineration[d]**	**Incineration[d]**
15	**Component**	**Weight[a] (lbs)**	**Volume[b] (yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(lbs)**
16	**Paper Products:**						
17	High Grade Office	2,336.0	15.6	1.17%	6.2	0.9	140.2
18	Corrugated	48,301.7	568.3	42.85%	227.3	28.4	2,415.1
19	Newsprint	182.5	1.2	0.09%	0.5	0.1	11.0
20	Magazines	5,304.7	35.4	2.67%	14.1	2.1	318.3
21	Mixed Paper	19,588.3	130.6	9.85%	52.2	7.8	1,175.3
22	**Food Waste:**	129,915.7	265.1	19.99%	132.6	13.3	6,495.8
23	**Containers:**						0.0
24	Glass	26,474.7	80.2	6.05%	72.2	78.6	25,945.2
25	Aluminum	4,440.8	16.4	1.24%	4.9	16.1	4,352.0
26	Bi-metal/Steel	8,212.5	54.8	4.13%	16.4	53.7	8,048.3
27	Plastic PETE (1)	2,190.0	19.9	1.50%	4.0	2.0	219.0
28	Plastic HDPE (2)	949.0	8.6	0.65%	1.7	0.9	94.9
29	**Other Plastics:**	8,918.2	81.1	6.11%	16.2	8.1	891.8
30	**Metals:**						0.0
31	Ferrous	669.2	1.2	0.09%	0.7	1.2	662.5
32	Nonferrous	1,703.3	6.3	0.48%	1.9	6.2	1,669.3
33	Other	2,798.3	5.2	0.39%	3.1	5.1	2,770.4

	A	B	C	D	E	F	G	H
34	**Wood:**	2,129.2	5.3	0.40%	2.1	0.1	31.9	
35	**Miscellaneous:**					0.0	0.0	
36	Textiles	2,165.7	19.7	1.48%	7.9	0.5	54.1	
37	Rubber	1,423.5	6.5	0.49%	2.6	0.6	142.4	
38	Leather	219.0	0.8	0.06%	0.3	0.1	21.9	
39	Dirt, ashes, etc.	3,078.2	3.8	0.29%	3.8	2.7	2,154.7	
40	**Totals:**	271,000	1,326	1.000	571	229	57,614	
41								
42	**Key:**							
43	[a] Data from Appendix D							
44	[b] Conversion from lbs to yd^3 made with MSW component specific weight data found in the table at the end of the appendix							
45	[c] Conversion made with MSW component compaction data found in the table at the end of the appendix							
46	[d] Conversion made with MSW component inert residue data found in the table at the end of the appendix							
47								
48	**Estimated Annual Volumes of Waste by MSW Management Technique(s) for Each Alternative in Appendix C**							
49		**Compacted**						
50		**Volume to**	**Volume to**	**Volume to**	**Volume to**			
51		**Landfill**	**Incinerate**	**Recycle**	**Compost**			
52	**Alternative**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**			
53	1	249	926	0.0	0.0			
54	2	232	926	57.0	0.0			
55	3	191	926	64.2	0.0			
56	4	174	926	121.1	0.0			
57	5	238	714	0.0	212.1			
58	6	221	714	57.0	212.1			
59	7	180	714	64.2	212.1			
60	8	163	714	121.1	212.1			
61	9	249	926	0.0	0.0			
62	10	232	926	57.0	0.0			
63	11	191	926	64.2	0.0			
64	12	174	926	121.1	0.0			
65	13	238	714	0.0	212.1			

	A	B	C	D	E	F	G	H
66	14	221	714	57.0	212.1			
67	15	180	714	64.2	212.1			
68	16	163	714	121.1	212.1			
69	17	571	0	0.0	0.0			
70	18	554	0	57.0	0.0			
71	19	513	0	64.2	0.0			
72	20	524	0	117.9	0.0			
73	21	571	0	454.6	0.0			
74	22	496	0	121.1	0.0			
75	23	507	0	174.9	0.0			
76	24	554	0	511.6	0.0			
77	25	466	0	182.1	0.0			
78	26	513	0	518.8	0.0			
79	27	342	0	572.5	0.0			
80	28	449	0	239.0	0.0			
81	29	496	0	575.7	0.0			
82	30	325	0	629.5	0.0			
83	31	284	0	636.7	0.0			
84	32	267	0	693.6	0.0			
85	33	418	0	0.0	330.0			
86	34	401	0	57.0	330.0			
87	35	360	0	64.2	330.0			
88	36	418	0	454.6	330.0			
89	37	343	0	121.1	330.0			
90	38	401	0	511.6	330.0			
91	39	360	0	518.8	330.0			
92	40	343	0	575.7	330.0			

	A	B	C	D	E	F	G	H
100	**Estimated Landfill Footprint for Each Alternative in Appendix C**							
101								
102								
103		**Waste**	**Multiply by**	**Add**	**Convert**	**Divide by**	**Multiply**	**Estimated**
104		**Disposed in**	**20-year Study**	**Daily Cover**	**to**	**Depth to**	**by Growth**	**Landfill**
105		**Landfill[e]**	**Period**	**(2 to 1)**	**Cubic Feet**	**Get Area**	**Factor**	**Footprint**
106	**Alternative**	**(yd^3/yr)**	**(yd^3)**	**(yd^3)**	**(ft^3)**	**(ft^2)**	**(ft^2)**	**(ft^2)**
107	1	248.6	4,973	7,459	201,393	25,174	50,348	50,348
108	2	231.5	4,631	6,946	187,552	23,444	46,888	46,888
109	3	190.9	3,817	5,726	154,605	19,326	38,651	38,651
110	4	173.8	3,476	5,213	140,764	17,596	35,191	35,191
111	5	238.0	4,761	7,141	192,803	24,100	48,201	48,201
112	6	220.9	4,419	6,628	178,962	22,370	44,740	44,740
113	7	180.3	3,605	5,408	146,015	18,252	36,504	36,504
114	8	163.2	3,264	4,895	132,174	16,522	33,043	33,043
115	9	248.6	4,973	7,459	201,393	25,174	50,348	50,348
116	10	231.5	4,631	6,946	187,552	23,444	46,888	46,888
117	11	190.9	3,817	5,726	154,605	19,326	38,651	38,651
118	12	173.8	3,476	5,213	140,764	17,596	35,191	35,191
119	13	238.0	4,761	7,141	192,803	24,100	48,201	48,201
120	14	220.9	4,419	6,628	178,962	22,370	44,740	44,740
121	15	180.3	3,605	5,408	146,015	18,252	36,504	36,504
122	16	163.2	3,264	4,895	132,174	16,522	33,043	33,043
123	17	571.0	11,419	17,129	462,479	57,810	115,620	115,620
124	18	553.9	11,077	16,616	448,638	56,080	112,159	112,159
125	19	513.2	10,264	15,396	415,691	51,961	103,923	103,923
126	20	523.8	10,476	15,714	424,278	53,035	106,070	106,070
127	21	571.0	11,419	17,129	462,479	57,810	115,620	115,620
128	22	496.1	9,922	14,883	401,850	50,231	100,462	100,462
129	23	506.7	10,134	15,201	410,437	51,305	102,609	102,609
130	24	553.9	11,077	16,616	448,638	56,080	112,159	112,159
131	25	466.0	9,321	13,981	377,490	47,186	94,373	94,373
132	26	513.2	10,264	15,396	415,691	51,961	103,923	103,923

	A	B	C	D	E	F	G	H
133	27	342.0	6,839	10,259	276,986	34,623	69,247	69,247
134	28	448.9	8,979	13,468	363,649	45,456	90,912	90,912
135	29	496.1	9,922	14,883	401,850	50,231	100,462	100,462
136	30	324.9	6,497	9,746	263,146	32,893	65,786	65,786
137	31	284.2	5,684	8,526	230,198	28,775	57,550	57,550
138	32	267.1	5,342	8,013	216,358	27,045	54,089	54,089
139	33	417.7	8,355	12,532	338,375	42,297	84,594	84,594
140	34	400.7	8,013	12,020	324,534	40,567	81,133	81,133
141	35	360.0	7,200	10,800	291,587	36,448	72,897	72,897
142	36	417.7	8,355	12,532	338,375	42,297	84,594	84,594
143	37	342.9	6,858	10,287	277,746	34,718	69,436	69,436
144	38	400.7	8,013	12,020	324,534	40,567	81,133	81,133
145	39	360.0	7,200	10,800	291,587	36,448	72,897	72,897
146	40	342.9	6,858	10,287	277,746	34,718	69,436	69,436
147								
148	**Key:**							
149	[e] Waste is assumed to be compacted							
150								
151	**Conversion Factors for MSW Components**							
152								
153			**Compaction**	**Inert Residue**				
154		**Specific**	**Factors for**	**After**				
155		**Weight[a]**	**Components**	**Incineration[c]**				
156	**Component**	**(lb/yd^3)**	**in Landfills[b]**	**(%)**				
157	**Paper Products:**							
158	High Grade Office	150	0.4	6%				
159	Corrugated	85	0.4	5%				
160	Newsprint	150	0.4	6%				
161	Magazines	150	0.4	6%				
162	Mixed Paper	150	0.4	6%				
163	**Food Waste:**	490	0.5	5%				
164	**Containers:**							

	A	B	C	D	E	F	G	H
165	Glass	330	0.9	98%				
166	Aluminum	270	0.3	98%				
167	Bi-metal/Steel	150	0.3	98%				
168	Plastic PETE (1)	110	0.2	10%				
169	Plastic HDPE (2)	110	0.2	10%				
170	**Other Plastics:**	110	0.2	10%				
171	**Metals:**							
172	Ferrous	540	0.6	99%				
173	Nonferrous	270	0.3	98%				
174	Other	540	0.6	99%				
175	**Wood:**	400	0.4	1.5%				
176	**Miscellaneous:**							
177	Textiles	110	0.4	2.5%				
178	Rubber	220	0.4	10%				
179	Leather	270	0.4	10%				
180	Dirt,ashes, etc.	800	1	70%				
181								
182	[a] (Tchobanoglous et al., 1993: 70)							
183	[b] (Tchobanoglous et al., 1993: 474)							
184	[c] (Tchobanoglous et al., 1993: 84)							

Appendix F: Data for Start-Up Cost Objective

In this appendix an order-of-magnitude cost estimate is calculated for each MSW management alternative presented in Appendix C. These cost estimates may be used for preliminary budgeting purposes. They included only direct capital construction costs and not design, permit fees, operations and maintenance, and closure and post-closure care costs. The data used in these order-of-magnitude cost estimates were derived from a number of sources, including vendor estimates, industry estimating data (RS Means), 611 CES environmental flight personnel, Eareckson base operations personnel, and recent cost estimates completed for the 611 CES on Eareckson Air Station's waste management system (Jacob's, 2000; United States Army Corps of Engineers, 2000; and Earth Tech, Inc., 1998). Actual cost for construction will depend on:

- actual labor and material costs;
- actual site conditions;
- productivity;
- competitive market conditions;
- final project scope;
- final project schedule; and
- selected firm to perform the construction.

As a result, the cost estimates prepared in this document will vary from the final project construction cost.

The waste stream characterization data presented in Table 11 of Chapter 4 was used to determine equipment requirements and the magnitude of construction for each alternative.

Model Assumptions:

General Assumptions

- Estimates based on RS Means 1997 costs will be adjusted to account for inflation at a rate of 4% per year.
- Geographic cost adjustment factor for Eareckson Air Station is 1.311 (Jacobs, 2000).
- Estimate assumes that the entire MSW management strategy is implemented at the same time.
- Fuel is available at Eareckson AS and is available to the construction contractor(s) at no cost.
- Construction materials and equipment are barged from Seattle.
- Recycling and composting equipment will be purchased by the 611 CES/CEV.
- Costs are all FY2000 costs.
- Life expectancy of all equipment is assumed to be 20 years.
- Existing vehicles and heavy equipment for MSW management at Eareckson will be used. No new equipment required.

Landfill Assumptions

- Adequate sand and gravel material are available at Eareckson AS at no cost.
- The landfill is square in shape.
- Square footage and cubic yard estimates are based on calculations and assumptions from Appendix F.
- The landfill composite liner system and leachate collection system are only applicable to Class II landfills.
- The current dumpsters, refuse truck, and heavy equipment used for landfill operations will continue to be used and no new equipment is required.

Incinerator Assumptions

- Adequate facilities already exist for incineration operations. Only minor renovations will be required.

Recycling Assumptions

- No costs to back-haul recyclable materials on military aircraft.
- No cost to transport recycling equipment on military aircraft
- The Elmendorf AFB Recycling Center will not charge any labor for picking up recyclables at the aircraft/flightline.
- Adequate facilities already exist for recycling operations.
- BOS Contractor will install equipment as an over and above project.

Composting Assumptions

- Adequate facilities already exist for composting operations. Only minor renovations will be required.
- In-vessel composter and equipment to be sent to Eareckson AS on the annual barge from Seattle

	A	B	C	D	E	F	G
1	**Start-Up Cost Data**						
2	**Model Assumptions:**						
3	Landfill Depth (ft)	8					
4	Eareckson AS Cost Adjustment	1.311					
5	Inflation (%/year)	4%					
6					**Adjusted**		
7	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Cost/Unit**	**Cost**	**Basis of Estimate**
8	***Class II MSWLF***						
9	**General Conditions/Site Work**						
10	Mobilization/Demobilization	1	LS	$400,000	$400,000	$400,000	(Jacobs, 2000)
11	Site Clearing	50,348	SF	$0.02	$0.03	$1,297	(RS Means, 1997)
12	Topsoil Stripping and Stockpiling	18,647	CY	$0.56	$0.80	$14,943	(RS Means, 1997)
13	Excavation	18,647	CY	$2.31	$3.31	$61,641	(RS Means, 1997)
14	Soil Compaction	932	CY	$1.01	$1.45	$1,348	(RS Means, 1997)
15	**Composite Liner System**						
16	Geosynthetic Clay Liner	50,348	SF	$0.70	$0.70	$35,244	(Jacobs, 2000)
17	60-mil HDPE Membrane Liner	50,348	SF	$0.80	$0.80	$40,279	(Jacobs, 2000)
18	**Leachate Collection System**						
19	Drainage/Bedding Material:						
20	Materials Loading	1,865	CY	$6.70	$9.59	$17,879	(RS Means, 1997)
21	Materials Hauling	1,865	CY	$4.91	$7.03	$13,102	(RS Means, 1997)
22	Backfilling	1,865	CY	$0.53	$0.76	$1,414	(RS Means, 1997)
23	3" PVC pipe	224	LF	$5.46	$5.46	$1,225	(Jacobs, 2000)
24	3" PVC pipe installation	224	LF	$9.41	$13.47	$3,021	(RS Means, 1997)
25	1" PVC pipe	2,293	LF	$1.01	$1.01	$2,316	(Jacobs, 2000)
26	1" PVC pipe installation	2,293	LF	$4.81	$6.88	$15,783	(RS Means, 1997)
27	**Final Cover System**						
28	Geosynthetic Clay Liner	52,866	SF	$0.70	$0.70	$37,006	(Jacobs, 2000)
29	60-mil HDPE Membrane Liner	52,866	SF	$0.80	$0.80	$42,293	(Jacobs, 2000)
30	Tundra Peat	979	CY	$0.58	$0.83	$813	(RS Means, 1997)
31							
32	**Total Direct Costs**					$689,603	

	A	B	C	D	E	F	G
33							
34	**Overhead (15% of direct costs)**					$103,441	
35	**Profit (10% of direct costs)**					$68,960	
36	**Bond (3% of direct costs)**					$20,688	
37							
38	**CLASS II LANDFILL TOTAL COST**					$882,692	
39							
40					**Adjusted**		
41	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Cost/Unit**	**Cost**	**Basis of Estimate**
42	***Class III MSWLF***						
43	**General Conditions/Site Work**						
44	Mobilization/Demobilization	1	LS	$400,000	$400,000	$400,000	(Jacobs, 2000)
45	Site Clearing	50,348	SF	$0.02	$0.03	$1,297	(RS Means, 1997)
46	Topsoil Stripping and Stockpiling	18,647	CY	$0.56	$0.80	$14,943	(RS Means, 1997)
47	Excavation	18,647	CY	$2.31	$3.31	$61,641	(RS Means, 1997)
48	Soil Compaction	932	CY	$1.01	$1.45	$1,348	(RS Means, 1997)
49	**Drainage/Bedding**						
50	Materials Loading	1,865	CY	$6.70	$9.59	$17,879	(RS Means, 1997)
51	Materials Hauling	1,865	CY	$4.91	$7.03	$13,102	(RS Means, 1997)
52	Backfilling	1,865	CY	$0.53	$0.76	$1,414	(RS Means, 1997)
53	**Final Cover System**						
54	Geosynthetic Clay Liner	52,866	SF	$0.70	$0.70	$37,006	(Jacobs, 2000)
55	60-mil HDPE Membrane Liner	52,866	SF	$0.80	$0.80	$42,293	(Jacobs, 2000)
56	Tundra Peat	979	CY	$0.58	$0.83	$813	(RS Means, 1997)
57							
58	**Total Direct Costs**					$591,735	
59							
60	**Overhead (15% of direct costs)**					$88,760	
61	**Profit (10% of direct costs)**					$59,174	
62	**Bond (3% of direct costs)**					$17,752	
63							
64	**CLASS III LANDFILL TOTAL COST**					$757,421	

	A	B	C	D	E	F	G
65							
66							
67	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Adjusted Cost/Unit**	**Cost**	**Basis of Estimate**
68	***Incinerator***						
69	Mobilization/Demobilization	1	LS	$350,000	$350,000	$350,000	(United States Army Corps of Engineers, 2000)
70	Incinerator	1	EA	$170,000	$170,000	$170,000	Vendor Quote[a]
71	Incinerator Building	1	LS	$150,000	$150,000	$150,000	(United States Army Corps of Engineers, 2000)
72	Installation and Training	1	LS	$15,000	$15,000	$15,000	(United States Army Corps of Engineers, 2000)
73							
74	**Total Direct Costs**					$685,000	
75							
76	**Overhead (15% of direct costs)**					$102,750	
77	**Profit (10% of direct costs)**					$68,500.0	
78	**Bond (3% of direct costs)**					$20,550	
79							
80	**INCINERATOR TOTAL COST**					$876,800	
81							
82	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Adjusted Cost/Unit**	**Cost**	**Basis of Estimate**
83	***Recycling***						
84	Baler (for cardboard aluminum, & tin cans)	1	EA	$13,995	$13,995	$13,995	Vendor Quote[b]
85	Baler Installation	1	LS	$1,500	$1,500	$1,500	Vendor Estimate[b]
86	Pulverizer (for glass)	1	EA	$21,000	$21,000	$21,000	Vendor Quote[c]
87	Pulverizer Installation	1	LS	$2,000	$2,000	$2,000	Vendor Estimate[c]
88	Recycling collection container (32 gal)	10	EA	$59.99	$59.99	$600	Vendor Quote[d]

	A	B	C	D	E	F	G
89	Recycling bins (23 gal)	20	EA	$29.99	$29.99	$600	Vendor Quote[d]
90	Recycling bins (13 quart)	40	EA	$5.12	$5.12	$205	Vendor Quote[d]
91							
92	**RECYCLING TOTAL COST**					$39,900	
93	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Adjusted Cost/Unit**	**Cost**	**Basis of Estimate**
94	***Composting***						
95	In-Vessel Composter	1	EA	$250,000	$250,000	$250,000	Vendor Quote[e]
96	Installation & Trainining	1	EA	$50,000	$50,000	$50,000	Vendor Estimate[e]
97	Shipping to Seattle	1	LS	$5,000	$5,000	$10,000	Vendor Estimate[e]
98	Barge from Seattle	1	LS	$50,000	$50,000	$50,000	(McCloud, 2000)
99							
100	**COMPOSTING TOTAL COST**					$360,000	
101							
102	**Equipment Manufacturers and Specifications:**						
103	[a] Incinerator Manufacturer: ACS Inc., 1999 Alpine Way, Bellingham WA 98226, 1-800-445-0243						
104	Model Number: CA-750 (MSW) Max Charge: 7.5 CY Buring Rate: 935 lbs/hr (actual rate depends on waste composition)						
105	[b] Baler Manufacturer: Orwak USA, Inc., 10820 Normandale Blvd, Minneapolis MN 55437, (612)881-9200						
106	Model Number: ORWAK 9020 Twin Bin Baler						
107	[c] Glass Pulverizer Manufacturer: TWG Machine Inc., P.O. Box 767, 42 East Main St, Honeoye NY 14471, (716)229-2669						
108	[d] Recycling Bins & Collection Containers: Office Depot, 6th Avenue, Anchorage AK 99577, www.officedepot.com						
109	[e] In-Vessel Composter Manufacturer: Wright Environmental Management Inc., www.wrightenvironmental.com						
110	. Max Charger: 750 lbs/day						

	H	I	J	K	L	M	N	O
1	**Start-Up Cost Estimates for Each Alternative in Appendix C**							
2								
3		**Estimated**	**Estimated**	**Estimated**	**Estimated**	**Estimated**	**Estimated**	**Total**
4		**Landfill**	**Landfill**	**Landfill**	**Incineration**	**Recycling**	**Composting**	**Estimated**
5		**Volume[a]**	**Footprint[b]**	**Cost**	**Cost**	**Cost**	**Cost**	**Cost**
6	**Alternative**	**(yd^3)**	**(ft^2)**	**($)**	**($)**	**($)**	**($)**	**($)**
7				*$757,421*				
8	1	7,459	50,348	$757,421	$876,800	$0	$0	$1,634,221
9	2	6,946	46,888	$740,554	$876,800	$16,900	$0	$1,634,254
10	3	5,726	38,651	$700,404	$876,800	$24,405	$0	$1,601,609
11	4	5,213	35,191	$683,538	$876,800	$39,900	$0	$1,600,237
12	5	7,141	48,201	$746,953	$876,800	$0	$360,000	$1,983,753
13	6	6,628	44,740	$730,086	$876,800	$16,900	$360,000	$1,983,786
14	7	5,408	36,504	$689,936	$876,800	$24,405	$360,000	$1,951,141
15	8	4,895	33,043	$673,069	$876,800	$39,900	$360,000	$1,949,769
16				*$882,692*				
17	9	7,459	50,348	$882,692	$876,800	$0	$0	$1,759,492
18	10	6,946	46,888	$857,323	$876,800	$16,900	$0	$1,751,023
19	11	5,726	38,651	$796,916	$876,800	$24,405	$0	$1,698,121
20	12	5,213	35,191	$771,531	$876,800	$39,900	$0	$1,688,230
21	13	7,141	48,201	$866,947	$876,800	$0	$360,000	$2,103,747
22	14	6,628	44,740	$841,576	$876,800	$16,900	$360,000	$2,095,275
23	15	5,408	36,504	$781,161	$876,800	$24,405	$360,000	$2,042,366
24	16	4,895	33,043	$755,772	$876,800	$39,900	$360,000	$2,032,472
25	17	17,129	115,620	$1,360,783	$0	$0	$0	$1,360,783
26	18	16,616	112,159	$1,335,452	$0	$16,900	$0	$1,352,352
27	19	15,396	103,923	$1,275,150	$0	$24,405	$0	$1,299,554
28	20	15,714	106,070	$1,290,868	$0	$1,405	$0	$1,292,272
29	21	17,129	115,620	$1,360,783	$0	$16,900	$0	$1,377,682
30	22	14,883	100,462	$1,249,815	$0	$39,900	$0	$1,289,715
31	23	15,201	102,609	$1,265,534	$0	$16,900	$0	$1,282,433
32	24	16,616	112,159	$1,335,452	$0	$16,900	$0	$1,352,352

	H	I	J	K	L	M	N	O
33	25	13,981	94,373	$1,205,223	$0	$24,405	$0	$1,229,627
34	26	15,396	103,923	$1,275,150	$0	$39,900	$0	$1,315,049
35	27	10,259	69,247	$1,021,191	$0	$16,900	$0	$1,038,090
36	28	13,468	90,912	$1,179,884	$0	$39,900	$0	$1,219,784
37	29	14,883	100,462	$1,249,815	$0	$39,900	$0	$1,289,715
38	30	9,746	65,786	$995,839	$0	$16,900	$0	$1,012,738
39	31	8,526	57,550	$935,479	$0	$39,900	$0	$975,378
40	32	8,013	54,089	$910,117	$0	$39,900	$0	$950,017
41	33	12,532	84,594	$1,133,610	$0	$0	$360,000	$1,493,610
42	34	12,020	81,133	$1,108,267	$0	$16,900	$360,000	$1,485,166
43	35	10,800	72,897	$1,047,932	$0	$24,405	$360,000	$1,432,336
44	36	12,532	84,594	$1,133,610	$0	$16,900	$360,000	$1,510,509
45	37	10,287	69,436	$1,022,582	$0	$39,900	$360,000	$1,422,481
46	38	12,020	81,133	$1,108,267	$0	$16,900	$360,000	$1,485,166
47	39	10,800	72,897	$1,047,932	$0	$39,900	$360,000	$1,447,831
48	40	10,287	69,436	$1,022,582	$0	$39,900	$360,000	$1,422,481
49								
50	**Key:**							
51	[a] From Appendix E							
52	[b] From Appendix E							

Appendix G: Data for Recurring O&M Cost Objective

In this appendix cost estimates are calculated for the operations and maintenance (O&M) of each MSW management alternative presented in Appendix C. The cost data used in these cost estimates were derived from industry estimates, Air Force cost estimating tools (AFCEEE, 1998), 611 CES environmental flight personnel, Eareckson AS base operations personnel, and recent cost estimates completed for the 611 CES on Eareckson Air Station's waste management system (Earth Tech, Inc., 1998). Actual O&M costs for will depend on:

- actual labor costs;
- productivity;
- final MSW system scope;
- actual utility costs; and
- modification to existing base operations support contract.

As a result, the cost estimates prepared in this document will vary from the final system O&M cost.

The waste stream characterization data presented in Table 11 of Chapter 4 was used to determine weight and volume estimates of waste materials to be handled by each alternative. This data is critical in that most O&M cost data is expressed in dollars per ton.

Model Assumptions:

- The model assumptions used in Appendix E apply to this appendix as well.
- Landfill & incineration O&M costs based on average tipping fees ($/ton) reported in BioCycle (Goldstein, 2000: 34) for the state of Alaska.
- Composting O&M costs based on an EPA (1999b: 12) report on onsite institutional composting program costs.
- Recycling O&M costs based on a feasibility study cost analysis conducted by the 611 CES (McCloud, 2000).

	A	B	C	D	E	F	G	H
1	**Data for Model Assumptions**							
2	Recovery Factor	80%						
3								
4	**Eareckson AS MSW Weight Estimates**							
5								
6								
7			**Weight**					
8		**Annual**	**After**					
9		**Estimated**	**Incineration[b]**					
10	**Component**	**Weight[a] (lbs)**	**(lbs)**					
11	**Paper Products:**							
12	High Grade Office	2,336	140.2					
13	Corrugated	48,302	2,415.1					
14	Newsprint	183	11.0					
15	Magazines	5,305	318.3					
16	Mixed Paper	19,588	1,175.3					
17	**Food Waste:**	129,916	6,495.8					
18	**Containers:**		0.0					
19	Glass	26,475	25,945.2					
20	Aluminum	4,441	4,352.0					
21	Bi-metal/Tin	8,213	8,048.3					
22	Plastic PETE (1)	2,190	219.0					
23	Plastic HDPE (2)	949	94.9					
24	**Other Plastics:**	8,918	891.8					
25	**Metals:**		0.0					
26	Ferrous	669	662.5					
27	Nonferrous	1,703	1,669.3					
28	Other	2,798	2,770.4					
29	**Wood:**	2,129	31.9					
30	**Miscellaneous:**		0.0					
31	Textiles	2,166	54.1					
32	Rubber	1,424	142.4					

	A	B	C	D	E	F	G	H
33	Leather	219	21.9					
34	Dirt, ashes, etc.	3,078	2,155					
35	**Totals:**	271,000	57,614					
36								
37	**Key:**							
38	[a] Data from Appendix D							
39	[b] Data from Appendix E							
40								
41	**Estimated Annual Weight (in lbs) of Waste by MSW Management Technique(s) for Each Alternative in Appendix C**							
42								
43				**Al Cans to**	**Steel Cans to**	**Glass to**	**Paper to**	**Cardboard to**
44		**Landfill**	**Incinerate**	**Recycle**	**Recycle**	**Recycle**	**Recycle**	**Recycle**
45	**Alternative**	**(lbs)**	**(lbs)**	**(lbs)**	**(lbs)**	**(lbs)**	**(lbs)**	**(lbs)**
46	1	101,711	178,899	0	0	0	0	0
47	2	91,588	178,899	3,553	6,570	0	0	0
48	3	80,531	178,899	0	0	21,180	0	0
49	4	70,409	178,899	3,553	6,570	21,180	0	0
50	5	96,514	74,966	0	0	0	0	0
51	6	86,392	74,966	3,553	6,570	0	0	0
52	7	75,335	74,966	0	0	21,180	0	0
53	8	65,212	74,966	3,553	6,570	21,180	0	0
54	9	101,711	178,899	0	0	0	0	0
55	10	91,588	178,899	3,553	6,570	0	0	0
56	11	80,531	178,899	0	0	21,180	0	0
57	12	70,409	178,899	3,553	6,570	21,180	0	0
58	13	96,514	74,966	0	0	0	0	0
59	14	86,392	74,966	3,553	6,570	0	0	0
60	15	75,335	74,966	0	0	21,180	0	0
61	16	65,212	74,966	3,553	6,570	21,180	0	0
62	17	271,000	0	0	0	0	0	0
63	18	260,878	0	3,553	6,570	0	0	0
64	19	249,821	0	0	0	21,180	0	0

	A	B	C	D	E	F	G	H
65	20	253,315	0	0	0	0	17,685	0
66	21	271,000	0	0	0	0	0	38,641
67	22	239,698	0	3,553	6,570	21,180	0	0
68	23	243,192	0	3,553	6,570	0	17,685	0
69	24	260,878	0	3,553	6,570	0	0	38,641
70	25	232,135	0	0	0	21,180	17,685	0
71	26	249,821	0	0	0	21,180	0	38,641
72	27	214,674	0	0	0	0	17,685	38,641
73	28	222,012	0	3,553	6,570	21,180	17,685	0
74	29	239,698	0	3,553	6,570	21,180	0	38,641
75	30	204,551	0	3,553	6,570	0	17,685	38,641
76	31	193,494	0	0	0	21,180	17,685	38,641
77	32	183,371	0	3,553	6,570	21,180	17,685	38,641
78	33	149,382	0	0	0	0	0	0
79	34	139,260	0	3,553	6,570	0	0	0
80	35	128,203	0	0	0	21,180	0	0
81	36	149,382	0	0	0	0	0	38,641
82	37	118,080	0	3,553	6,570	21,180	0	0
83	38	139,260	0	3,553	6,570	0	0	38,641
84	39	128,203	0	0	0	21,180	0	38,641
85	40	118,080	0	3,553	6,570	21,180	0	38,641
86								

	A	B	C	D	E	F	G	H
87	Estimated Annual Weight (in Tons) of Waste by MSW Management Technique(s) for Each Alternative in Appendix C							
88								
89				Al Cans to	Steel Cans	Glass to	Paper to	Cardboard to
90		Landfill	Incinerate	Recycle	to Recycle	Recycle	Recycle	Recycle
91	Alternative	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)
92	1	51	89	0	0	0	0	0
93	2	46	89	2	3	0	0	0
94	3	40	89	0	0	11	0	0
95	4	35	89	2	3	11	0	0
96	5	48	37	0	0	0	0	0
97	6	43	37	2	3	0	0	0
98	7	38	37	0	0	11	0	0
99	8	33	37	2	3	11	0	0
100	9	51	89	0	0	0	0	0
101	10	46	89	2	3	0	0	0
102	11	40	89	0	0	11	0	0
103	12	35	89	2	3	11	0	0
104	13	48	37	0	0	0	0	0
105	14	43	37	2	3	0	0	0
106	15	38	37	0	0	11	0	0
107	16	33	37	2	3	11	0	0
108	17	136	0	0	0	0	0	0
109	18	130	0	2	3	0	0	0
110	19	125	0	0	0	11	0	0
111	20	127	0	0	0	0	9	0
112	21	136	0	0	0	0	0	19
113	22	120	0	2	3	11	0	0
114	23	122	0	2	3	0	9	0
115	24	130	0	2	3	0	0	19
116	25	116	0	0	0	11	9	0
117	26	125	0	0	0	11	0	19
118	27	107	0	0	0	0	9	19

	A	B	C	D	E	F	G	H
119	28	111	0	2	3	11	9	0
120	29	120	0	2	3	11	0	19
121	30	102	0	2	3	0	9	19
122	31	97	0	0	0	11	9	19
123	32	92	0	2	3	11	9	19
124	33	75	0	0	0	0	0	0
125	34	70	0	2	3	0	0	0
126	35	64	0	0	0	11	0	0
127	36	75	0	0	0	0	0	19
128	37	59	0	2	3	11	0	0
129	38	70	0	2	3	0	0	19
130	39	64	0	0	0	11	0	19
131	40	59	0	2	3	11	0	19
132	**Recurring O&M Cost Data for Year 2000**							
133								
134								
135	**Item**	**Quantity**	**Unit**	**Cost/Unit**	**Cost**	**Basis of Estimate**		
136	**Class III Landfill**							
137	Collection	78	Hrs	$30	$0	(Jones, 2000)		
138	O&M	0	Ton	$70	$0	(Goldstein, 2000: 34)		
139	***Total Cost***				$0			
140								
141	**Class II Landfill**							
142	Collection	78	Hrs	$30	$0	(Jones, 2000)		
143	O&M	0	Ton	$70	$0	(Goldstein, 2000: 34)		
144	Leachate Testing	1	LS	$20,000	$0	(McCloud, 2000)		
145	***Total Cost***				$0			
146								
147	**Incineration**							
148	Collection	78	Hrs	$30	$0	(McCloud, 2000)		
149	O&M	0	Ton	$80	$0	(Goldstein, 2000: 34)		
150	***Total Cost***				$0			

	A	B	C	D	E	F	G	H
151								
152	**Recycling**							
153	*Costs:*					(McCloud, 2000)		
154	Aluminum Cans	0	Ton	$782	$0			
155	Steel Cans	0	Ton	$50	$0			
156	Glass	0	Ton	$249	$0			
157	Paper	0	Ton	$256	$0			
158	Cardboard	0	Ton	$100	$0			
159	*Material Sales:*					(Paige, 2000)		
160	Aluminum Cans	0	Ton	$800	$0			
161	Steel Cans	0	Ton	$40	$0			
162	Glass	0	Ton	$0	$0			
163	Paper	0	Ton	$0	$0			
164	Cardboard	0	Ton	$20	$0			
165	*Cost - Benefits*							
166	Aluminum Cans				$0			
167	Steel Cans				$0			
168	Glass				$0			
169	Paper				$0			
170	Cardboard				$0			
171								
172	**Composting**							
173	Collection	156	Hrs	$30	$0	(McCloud, 2000)		
174	O&M	0	Ton	$98	$0	(USEPA, 1999b: 12)		
175	***Total Cost***				$0			

	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	**Recurring O&M Cost for Year 2000 for Each Alternative in Appendix C**																
2						**Alum Cans**		**Steel Cans**		**Glass**		**Paper**		**CB**			
3		**Landfill**		**Incinerate**		**Recycle**		**Recycle**		**Recycle**		**Recycle**		**Recycle**		**Compost**	
4	**Alt**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**	**(Tons)**	**Cost**
5			$0		$0		$0		$0		$0		$0		$0		$0
6	1	51	$5,900	89	$9,496	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
7	2	46	$5,546	89	$9,496	2	($32)	3	$33	0	$0	0	$0	0	$0	0	$0
8	3	40	$5,159	89	$9,496	0	$0	0	$0	11	$2,637	0	$0	0	$0	0	$0
9	4	35	$4,804	89	$9,496	2	($32)	3	$33	11	$2,637	0	$0	0	$0	0	$0
10	5	48	$5,718	37	$5,339	0	$0	0	$0	0	$0	0	$0	0	$0	52	$9,773
11	6	43	$5,364	37	$5,339	2	($32)	3	$33	0	$0	0	$0	0	$0	52	$9,773
12	7	38	$4,977	37	$5,339	0	$0	0	$0	11	$2,637	0	$0	0	$0	52	$9,773
13	8	33	$4,622	37	$5,339	2	($32)	3	$33	11	$2,637	0	$0	0	$0	52	$9,773
14			$0		$0		$0		$0		$0		$0		$0		$0
15	9	51	$25,900	89	$9,496	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
16	10	46	$25,546	89	$9,496	2	($32)	3	$33	0	$0	0	$0	0	$0	0	$0
17	11	40	$25,159	89	$9,496	0	$0	0	$0	11	$2,637	0	$0	0	$0	0	$0
18	12	35	$24,804	89	$9,496	2	($32)	3	$33	11	$2,637	0	$0	0	$0	0	$0
19	13	48	$25,718	37	$5,339	0	$0	0	$0	0	$0	0	$0	0	$0	52	$9,773
20	14	43	$25,364	37	$5,339	2	($32)	3	$33	0	$0	0	$0	0	$0	52	$9,773
21	15	38	$24,977	37	$5,339	0	$0	0	$0	11	$2,637	0	$0	0	$0	52	$9,773
22	16	33	$24,622	37	$5,339	2	($32)	3	$33	11	$2,637	0	$0	0	$0	52	$9,773
23	17	136	$31,825	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
24	18	130	$31,471	0	$0	2	($32)	3	$33	0	$0	0	$0	0	$0	0	$0
25	19	125	$31,084	0	$0	0	$0	0	$0	11	$2,637	0	$0	0	$0	0	$0
26	20	127	$31,206	0	$0	0	$0	0	$0	0	$0	9	$2,264	0	$0	0	$0
27	21	136	$31,825	0	$0	0	$0	0	$0	0	$0	0	$0	19	$1,546	0	$0
28	22	120	$30,729	0	$0	2	($32)	3	$33	11	$2,637	0	$0	0	$0	0	$0
29	23	122	$30,852	0	$0	2	($32)	3	$33	0	$0	9	$2,264	0	$0	0	$0
30	24	130	$31,471	0	$0	2	($32)	3	$33	0	$0	0	$0	19	$1,546	0	$0
31	25	116	$30,465	0	$0	0	$0	0	$0	11	$2,637	9	$2,264	0	$0	0	$0
32	26	125	$31,084	0	$0	0	$0	0	$0	11	$2,637	0	$0	19	$1,546	0	$0

	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
33	27	107	$29,854	0	$0	0	$0	0	$0	0	$0	9	$2,264	19	$1,546	0	$0
34	28	111	$30,110	0	$0	2	($32)	3	$33	11	$2,637	9	$2,264	0	$0	0	$0
35	29	120	$30,729	0	$0	2	($32)	3	$33	11	$2,637	0	$0	19	$1,546	0	$0
36	30	102	$29,499	0	$0	2	($32)	3	$33	0	$0	9	$2,264	19	$1,546	0	$0
37	31	97	$29,112	0	$0	0	$0	0	$0	11	$2,637	9	$2,264	19	$1,546	0	$0
38	32	92	$28,758	0	$0	2	($32)	3	$33	11	$2,637	9	$2,264	19	$1,546	0	$0
39	33	75	$27,568	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	61	$10,639
40	34	70	$27,214	0	$0	2	($32)	3	$33	0	$0	0	$0	0	$0	61	$10,639
41	35	64	$26,827	0	$0	0	$0	0	$0	11	$2,637	0	$0	0	$0	61	$10,639
42	36	75	$27,568	0	$0	0	$0	0	$0	0	$0	0	$0	19	$1,546	61	$10,639
43	37	59	$26,473	0	$0	2	($32)	3	$33	11	$2,637	0	$0	0	$0	61	$10,639
44	38	70	$27,214	0	$0	2	($32)	3	$33	0	$0	0	$0	19	$1,546	61	$10,639
45	39	64	$26,827	0	$0	0	$0	0	$0	11	$2,637	0	$0	19	$1,546	61	$10,639
46	40	59	$26,473	0	$0	2	($32)	3	$33	11	$2,637	0	$0	19	$1,546	61	$10,639
47																	
48		**FY00**															
49	**Alt**	**Cost**															
50																	
51	1	$15,396															
52	2	$15,042															
53	3	$17,291															
54	4	$16,938															
55	5	$20,829															
56	6	$20,476															
57	7	$22,725															
58	8	$22,372															
59	9	$35,396															
60	10	$35,042															
61	11	$37,291															
62	12	$36,938															
63	13	$40,829															
64	14	$40,476															

	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
65	15	$42,725															
66	16	$42,372															
67	17	$31,825															
68	18	$31,472															
69	19	$33,721															
70	20	$33,470															
71	21	$33,371															
72	22	$33,367															
73	23	$33,116															
74	24	$33,017															
75	25	$35,365															
76	26	$35,266															
77	27	$33,663															
78	28	$35,012															
79	29	$34,913															
80	30	$33,310															
81	31	$35,559															
82	32	$35,205															
83	33	$38,208															
84	34	$37,854															
85	35	$40,103															
86	36	$39,753															
87	37	$39,750															
88	38	$39,400															
89	39	$41,649															
90	40	$41,295															

Appendix H: Data for Waste Diversion Objective

This appendix contains the spreadsheet model used to calculate the percentage waste diversion for each alternative in Appendix C.

	A	B	C	D
1	**Appendix H: Data for Waste Diversion Objective**			
2				
3	**Data for Model Assumptions**			
4	Recovery Factor	80%		
5				
6	**% Waste Diversion Estimates for Each Alternative in Appendix C**			
7				
8		**Weight**	**Weight**	**%**
9		**Recycled[a]**	**Composted[b]**	**Waste**
10	**Alternative**	**(lbs)**	**(lbs)**	**Diversion**
11	1	0	0	0.0%
12	2	10,123	0	3.7%
13	3	21,180	0	7.8%
14	4	31,302	0	11.6%
15	5	0	103,933	38.4%
16	6	10,123	103,933	42.1%
17	7	21,180	103,933	46.2%
18	8	31,302	103,933	49.9%
19	9	0	0	0.0%
20	10	10,123	0	3.7%
21	11	21,180	0	7.8%
22	12	31,302	0	11.6%
23	13	0	103,933	38.4%
24	14	10,123	103,933	42.1%
25	15	21,180	103,933	46.2%
26	16	31,302	103,933	49.9%
27	17	0	0	0.0%
28	18	10,123	0	3.7%
29	19	21,180	0	7.8%
30	20	17,685	0	6.5%
31	21	38,641	0	14.3%
32	22	31,302	0	11.6%

	A	B	C	D
33	23	27,808	0	10.3%
34	24	48,764	0	18.0%
35	25	38,865	0	14.3%
36	26	59,821	0	22.1%
37	27	56,327	0	20.8%
38	28	48,988	0	18.1%
39	29	69,944	0	25.8%
40	30	66,449	0	24.5%
41	31	77,507	0	28.6%
42	32	87,629	0	32.3%
43	33	0	121,618	44.9%
44	34	10,123	121,618	48.6%
45	35	21,180	121,618	52.7%
46	36	38,641	121,618	59.1%
47	37	31,302	121,618	56.4%
48	38	48,764	121,618	62.9%
49	39	59,821	121,618	67.0%
50	40	69,944	121,618	70.7%
51				
52	**Key:**			
53	[a] From Appendix G			
54	[b] From Appendix G			

Appendix I: Data for Implementation Time Objective

This appendix contains the spreadsheet data for implementation time for each alternative in Appendix C. The 611 CES/CEV staff provided the estimates (McCloud, 2000).

	A	B	C	D	E	F
1	**Category**	**Landfill**	**Incineration**	**Composting**	**Recycling**	**Implementation Time (yrs)**
2	1	x			x	1.5
3	2	x			x	2.5
4	3	x		x		2.5
5	4	x	x	x		3.5
6	5	x	x		x	3.5
7	6	x	x	x	x	3.5
8	7	x		x		1.5
9	8	x	x			3.5
10						
11	**Key:**					
12	x = Technique is includes in the category.					

Appendix J: Data for CEV Overhead Objective

This appendix contains the spreadsheet data for CEV overhead (in manhours) for each alternative in Appendix C. The 611 CES/CEV staff provided the overhead estimates (McCloud, 2000).

	A	B	C	D	E
1	**CEV Overhead Data**				
2					
3		**Estimated**			
4		**Overhead**			
5		**(Hrs)**			
6	Class III LF	40			
7	Class II LF	50			
8	Incineration	50			
9	Recycling	16			
10	Composting	24			
11					
12	**Alternative**	**CEV Overhead (MHs)**			
13	1	90			
14	2	106			
15	3	106			
16	4	106			
17	5	114			
18	6	130			
19	7	130			
20	8	130			
21	9	100			
22	10	116			
23	11	116			
24	12	116			
25	13	124			
26	14	140			
27	15	140			
28	16	140			

	A	B	C	D	E
12	**Alternative**	**CEV Overhead (MHs)**			
29	17	50			
30	18	66			
31	19	66			
32	20	66			
33	21	66			
34	22	66			
35	23	66			
36	24	66			
37	25	66			
38	26	66			
39	27	66			
40	28	66			
41	29	66			
42	30	66			
43	31	66			
44	32	66			
45	33	74			
46	34	90			
47	35	90			
48	36	90			
49	37	90			
50	38	90			
51	39	90			
52	40	90			

Appendix K: Eareckson Air Station Decision Support Model

In this appendix, the value functions, value hierarchy weights, and alternative scores presented in Chapter 4 are combined together in a spreadsheet to form the Eareckson Air Station (AS) decision support model. An overall, additive value function is used in the model to calculate the overall value of each alternative. As discussed in Chapter 2, the additive value function is simply a weighted average of the various objective value functions. The overall value function rank orders the model alternatives in a way that is consistent with the decision-maker's preferences for those outcomes.

	A	B	C	D	E	F	G	H	I	J
1	**Appendix K: Eareckson Air Station MSW Decision Support Model**									
2										
3	**Value Functions & Weights**									
4	**Lowest Tier Objectives**	**X**	**Value Functions**	**Local Weight**	**Global Weights**					
5	Facility Size	52000	1.00	0.286	0.121					
6	Start-Up Cost	1000000	1.00	0.457	0.194					
7	O&M Cost	10000	1.00	0.143	0.061					
8	Facility Location	0	1.00	0.114	0.049					
9	Waste Diversion	50	1.00	1	0.143					
10	Implementation Time	1	1.00	1	0.071					
11	CEV Overhead	40	1.00	0.546	0.194					
12	Liability to AF	2	1.00	0.182	0.065					
13	Impact to Env	1	1.00	0.273	0.097					
14					1.00					
15	**Second Tier Objectives**		**Value Functions**							
16	Resources		1.00	0.429						
17	Waste Diversion		1.00	0.143						
18	Implementation Time		1.00	0.071						
19	Compliance Burden		1.00	0.357						
20										
21	**Overall Objective**		**Overall Value Function**							
22	20-Yr Compliant MSW System		1.00							

	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	**Scores & Values for Each Alternative**														
2															
3		**Facility Size**		**Start-Up Cost**		**Recurring O&M Cost**		**Facility Location**		**Waste Diversion**		**Implement Time**		**CEV Overhead**	
4	**Alternative**	**Score (SF)**	**Value**	**Score ($)**	**Value**	**Score ($)**	**Value**	**Score (mi)**	**Value**	**Score (%)**	**Value**	**Score (yrs)**	**Value**	**Score (MHs)**	**Value**
5			**1.00**		**1.00**		**1.00**		**1.00**		**1.00**		**1.00**		**1.00**
6	1	50,348	1.00	$1,634,221	0.84	$15,396	0.87	0	1.00	0.00	0.00	3.5	0.45	90	0.58
7	2	46,888	1.00	$1,634,254	0.84	$15,042	0.87	0	1.00	3.74	0.19	3.5	0.45	106	0.45
8	3	38,651	1.00	$1,601,609	0.85	$17,291	0.82	0	1.00	7.82	0.39	3.5	0.45	106	0.45
9	4	35,191	1.00	$1,600,237	0.85	$16,938	0.83	0	1.00	11.55	0.55	3.5	0.45	106	0.45
10	5	48,201	1.00	$1,983,753	0.75	$20,829	0.73	0	1.00	38.35	0.94	3.5	0.45	114	0.38
11	6	44,740	1.00	$1,983,786	0.75	$20,476	0.74	0	1.00	42.09	0.96	3.5	0.45	130	0.25
12	7	36,504	1.00	$1,951,141	0.76	$22,725	0.68	0	1.00	46.17	0.98	3.5	0.45	130	0.25
13	8	33,043	1.00	$1,949,769	0.76	$22,372	0.69	0	1.00	49.90	1.00	3.5	0.45	130	0.25
14	9	50,348	1.00	$1,759,492	0.81	$35,396	0.37	0.5	0.75	0.00	0.00	3.5	0.45	100	0.50
15	10	46,888	1.00	$1,751,023	0.81	$35,042	0.37	0.5	0.75	3.74	0.19	3.5	0.45	116	0.37
16	11	38,651	1.00	$1,698,121	0.83	$37,291	0.32	0.5	0.75	7.82	0.39	3.5	0.45	116	0.37
17	12	35,191	1.00	$1,688,230	0.83	$36,938	0.33	0.5	0.75	11.55	0.55	3.5	0.45	116	0.37
18	13	48,201	1.00	$2,103,747	0.72	$40,829	0.23	0.5	0.75	38.35	0.94	3.5	0.45	124	0.30
19	14	44,740	1.00	$2,095,275	0.73	$40,476	0.24	0.5	0.75	42.09	0.96	3.5	0.45	140	0.17
20	15	36,504	1.00	$2,042,366	0.74	$42,725	0.18	0.5	0.75	46.17	0.98	3.5	0.45	140	0.17
21	16	33,043	1.00	$2,032,472	0.74	$42,372	0.19	0.5	0.75	49.90	1.00	3.5	0.45	140	0.17
22	17	115,620	0.00	$1,360,783	0.91	$31,825	0.45	0.5	0.75	0.00	0.00	1.5	0.95	50	0.92
23	18	112,159	0.00	$1,352,352	0.91	$31,472	0.46	0.5	0.75	3.74	0.19	1.5	0.95	66	0.78
24	19	103,923	0.00	$1,299,554	0.93	$33,721	0.41	0.5	0.75	7.82	0.39	1.5	0.95	66	0.78

	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
25	20	106,070	0.00	$1,292,272	0.93	$33,470	0.41	0.5	0.75	6.53	0.33	1.5	0.95	66	0.78
26	21	115,620	0.00	$1,377,682	0.91	$33,371	0.42	0.5	0.75	14.26	0.63	1.5	0.95	66	0.78
27	22	100,462	0.02	$1,289,715	0.93	$33,367	0.42	0.5	0.75	11.55	0.55	1.5	0.95	66	0.78
28	23	102,609	0.01	$1,282,433	0.93	$33,116	0.42	0.5	0.75	10.26	0.51	1.5	0.95	66	0.78
29	24	112,159	0.00	$1,352,352	0.91	$33,017	0.42	0.5	0.75	17.99	0.74	1.5	0.95	66	0.78
30	25	94,373	0.05	$1,229,627	0.94	$35,365	0.37	0.5	0.75	14.34	0.63	1.5	0.95	66	0.78
31	26	103,923	0.00	$1,315,049	0.92	$35,266	0.37	0.5	0.75	22.07	0.82	1.5	0.95	66	0.78
32	27	69,247	0.77	$1,038,090	0.99	$33,663	0.41	0.5	0.75	20.78	0.81	1.5	0.95	66	0.78
33	28	90,912	0.12	$1,219,784	0.95	$35,012	0.37	0.5	0.75	18.08	0.74	1.5	0.95	66	0.78
34	29	100,462	0.02	$1,289,715	0.93	$34,913	0.38	0.5	0.75	25.81	0.86	1.5	0.95	66	0.78
35	30	65,786	0.86	$1,012,738	1.00	$33,310	0.42	0.5	0.75	24.52	0.85	1.5	0.95	66	0.78
36	31	57,550	0.97	$975,378	1.00	$35,559	0.36	0.5	0.75	28.60	0.89	1.5	0.95	66	0.78
37	32	54,089	0.99	$950,017	1.00	$35,205	0.37	0.5	0.75	32.34	0.91	1.5	0.95	66	0.78
38	33	84,594	0.29	$1,493,610	0.88	$38,208	0.29	0.5	0.75	44.88	0.97	2.5	0.75	74	0.72
39	34	81,133	0.40	$1,485,166	0.88	$37,854	0.30	0.5	0.75	48.61	0.99	2.5	0.75	90	0.58
40	35	72,897	0.66	$1,432,336	0.89	$40,103	0.25	0.5	0.75	52.69	1.00	2.5	0.75	90	0.58
41	36	84,594	0.29	$1,510,509	0.87	$39,753	0.26	0.5	0.75	59.14	1.00	2.5	0.75	90	0.58
42	37	69,436	0.77	$1,422,481	0.89	$39,750	0.26	0.5	0.75	56.43	1.00	2.5	0.75	90	0.58
43	38	81,133	0.40	$1,485,166	0.88	$39,400	0.27	0.5	0.75	62.87	1.00	2.5	0.75	90	0.58
44	39	72,897	0.66	$1,447,831	0.89	$41,649	0.21	0.5	0.75	66.95	1.00	2.5	0.75	90	0.58
45	40	69,436	0.77	$1,422,481	0.89	$41,295	0.22	0.5	0.75	70.69	1.00	2.5	0.75	90	0.58

	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
1											
2											
3		**Liability to AF**		**Impact to Env**		**Total Value**	**Weghted**				
4	**Alternative**	**Score (permits)**	**Value**	**Score[a]**	**Value**	**(Unweighted)**	**Total Value**				
5			**1.00**		**1.00**						
6	1	3	0.67	8	0	5.41	**0.57**				
7	2	3	0.67	4	0.5	5.97	**0.62**				
8	3	3	0.67	4	0.5	6.12	**0.65**				
9	4	3	0.67	4	0.5	6.29	**0.67**				
10	5	4	0.33	6	0.4	5.99	**0.66**				
11	6	4	0.33	5	0.45	5.94	**0.64**				
12	7	4	0.33	5	0.45	5.91	**0.65**				
13	8	4	0.33	5	0.45	5.94	**0.65**				
14	9	3	0.67	8	0	4.54	**0.51**				
15	10	3	0.67	4	0.5	5.11	**0.56**				
16	11	3	0.67	4	0.5	5.27	**0.59**				
17	12	3	0.67	4	0.5	5.43	**0.61**				
18	13	4	0.33	6	0.4	5.13	**0.60**				
19	14	4	0.33	5	0.45	5.07	**0.58**				
20	15	4	0.33	5	0.45	5.05	**0.58**				
21	16	4	0.33	5	0.45	5.08	**0.59**				
22	17	2	1.00	7	0.1	5.08	**0.56**				
23	18	2	1.00	1	1	6.05	**0.65**				
24	19	2	1.00	1	1	6.21	**0.68**				

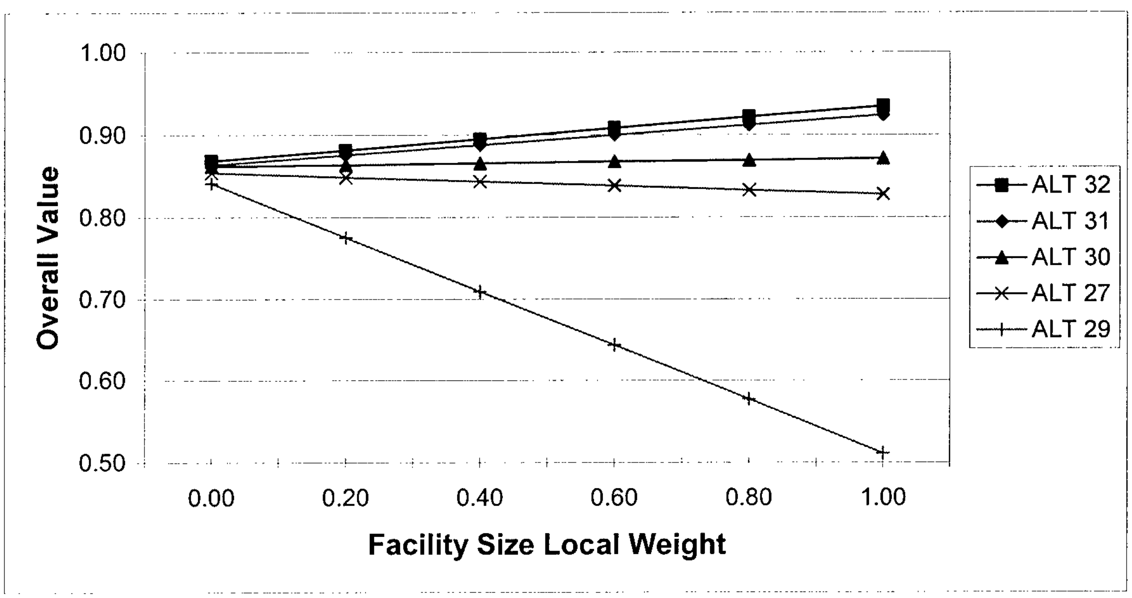
	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
25	20	2	1.00	1	1	6.15	**0.67**				
26	21	2	1.00	1	1	6.43	**0.71**				
27	22	2	1.00	1	1	6.39	**0.70**				
28	23	2	1.00	1	1	6.35	**0.70**				
29	24	2	1.00	1	1	6.56	**0.73**				
30	25	2	1.00	1	1	6.47	**0.72**				
31	26	2	1.00	1	1	6.59	**0.74**				
32	27	2	1.00	1	1	7.46	**0.84**				
33	28	2	1.00	1	1	6.66	**0.74**				
34	29	2	1.00	1	1	6.66	**0.75**				
35	30	2	1.00	1	1	7.61	**0.86**				
36	31	2	1.00	1	1	7.70	**0.88**				
37	32	2	1.00	1	1	7.75	**0.88**				
38	33	3	0.67	3	0.9	6.22	**0.72**				
39	34	3	0.67	2	0.95	6.27	**0.72**				
40	35	3	0.67	2	0.95	6.50	**0.75**				
41	36	3	0.67	2	0.95	6.12	**0.70**				
42	37	3	0.67	2	0.95	6.62	**0.76**				
43	38	3	0.67	2	0.95	6.24	**0.72**				
44	39	3	0.67	2	0.95	6.46	**0.75**				
45	40	3	0.67	2	0.95	6.58	**0.76**				

	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU
1	**Alternative**	**Size**	**SU Cost**	**O&M Cost**	**Location**	**Waste Div**	**Imp Time**	**Overhead**	**Liability**	**Impact**	**Total**
2	32	0.12	0.19	0.02	0.04	0.13	0.07	0.15	0.07	0.10	0.885
3	31	0.12	0.19	0.02	0.04	0.13	0.07	0.15	0.07	0.10	0.879
4	30	0.10	0.19	0.03	0.04	0.12	0.07	0.15	0.07	0.10	0.862
5	27	0.09	0.19	0.02	0.04	0.12	0.07	0.15	0.07	0.10	0.844
6	37	0.09	0.17	0.02	0.04	0.14	0.05	0.11	0.04	0.09	0.764
7	40	0.09	0.17	0.01	0.04	0.14	0.05	0.11	0.04	0.09	0.762
8	35	0.08	0.17	0.02	0.04	0.14	0.05	0.11	0.04	0.09	0.750
9	39	0.08	0.17	0.01	0.04	0.14	0.05	0.11	0.04	0.09	0.747
10	29	0.00	0.18	0.02	0.04	0.12	0.07	0.15	0.07	0.10	0.746
11	28	0.01	0.18	0.02	0.04	0.11	0.07	0.15	0.07	0.10	0.745
12	26	0.00	0.18	0.02	0.04	0.12	0.07	0.15	0.07	0.10	0.737
13	23	0.00	0.18	0.03	0.04	0.11	0.07	0.15	0.07	0.10	0.727
14	33	0.03	0.17	0.02	0.04	0.14	0.05	0.14	0.04	0.09	0.722
15	25	0.01	0.18	0.02	0.04	0.09	0.07	0.15	0.07	0.10	0.719
16	34	0.05	0.17	0.02	0.04	0.14	0.05	0.11	0.04	0.09	0.718
17	38	0.05	0.17	0.02	0.04	0.14	0.05	0.11	0.04	0.09	0.717
18	21	0.00	0.18	0.03	0.04	0.09	0.07	0.15	0.07	0.10	0.709
19	22	0.00	0.18	0.03	0.04	0.08	0.07	0.15	0.07	0.10	0.704
20	36	0.03	0.17	0.02	0.04	0.14	0.05	0.11	0.04	0.09	0.701
21	23	0.00	0.18	0.03	0.04	0.07	0.07	0.15	0.07	0.10	0.698
22	19	0.00	0.18	0.02	0.04	0.06	0.07	0.15	0.07	0.10	0.678
23	4	0.12	0.16	0.05	0.05	0.08	0.03	0.09	0.04	0.05	0.675
24	20	0.00	0.18	0.03	0.04	0.05	0.07	0.15	0.07	0.10	0.670
25	5	0.12	0.15	0.04	0.05	0.13	0.03	0.07	0.02	0.04	0.662
26	3	0.12	0.16	0.05	0.05	0.06	0.03	0.09	0.04	0.05	0.652
27	18	0.00	0.18	0.03	0.04	0.03	0.07	0.15	0.07	0.10	0.650
28	8	0.12	0.15	0.04	0.05	0.14	0.03	0.05	0.02	0.04	0.649

	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU
1	**Alternative**	**Size**	**SU Cost**	**O&M Cost**	**Location**	**Waste Div**	**Imp Time**	**Overhead**	**Liability**	**Impact**	**Total**
29	7	0.12	0.15	0.04	0.05	0.14	0.03	0.05	0.02	0.04	0.645
30	6	0.12	0.15	0.05	0.05	0.14	0.03	0.05	0.02	0.04	0.644
31	2	0.12	0.16	0.05	0.05	0.03	0.03	0.09	0.04	0.05	0.624
32	12	0.12	0.16	0.02	0.04	0.08	0.03	0.07	0.04	0.05	0.611
33	13	0.12	0.14	0.01	0.04	0.13	0.03	0.06	0.02	0.04	0.597
34	11	0.12	0.16	0.02	0.04	0.06	0.03	0.07	0.04	0.05	0.588
35	16	0.12	0.14	0.01	0.04	0.14	0.03	0.03	0.02	0.04	0.586
36	15	0.12	0.14	0.01	0.04	0.14	0.03	0.03	0.02	0.04	0.582
37	14	0.12	0.14	0.01	0.04	0.14	0.03	0.03	0.02	0.04	0.580
38	1	0.12	0.16	0.05	0.05	0.00	0.03	0.11	0.04	0.00	0.574
39	17	0.00	0.18	0.03	0.04	0.00	0.07	0.18	0.07	0.01	0.561
40	10	0.12	0.16	0.02	0.04	0.03	0.03	0.07	0.04	0.05	0.560
41	9	0.12	0.16	0.02	0.04	0.00	0.03	0.10	0.04	0.00	0.509

Appendix L. Sensitivity Analysis Graphs

The following graphs support the sensitivity analysis on the local weights (third-tier) discussed in Chapter 4. The rankings of the top 4 model alternatives were found to be totally insensitive to these objectives. As an example, Figure 42 illustrates the sensitivity analysis on the *Facility Size* objective local weight. As the facility size objective weight is varied from 0 to 1, Alternative 32 is the best alternative over the entire weight range (0 – 1.0). The second, third, and fourth ranked alternatives (31, 30, and 27) at the nominal weight value remain unchanged over the entire weight range as well. This insensitivity can be attributed to the fact that the top four model alternatives



receive nearly the same or exactly the same amount of value for all objectives.

Figure 42. Sensitivity Analysis on Facility Size Local Weight

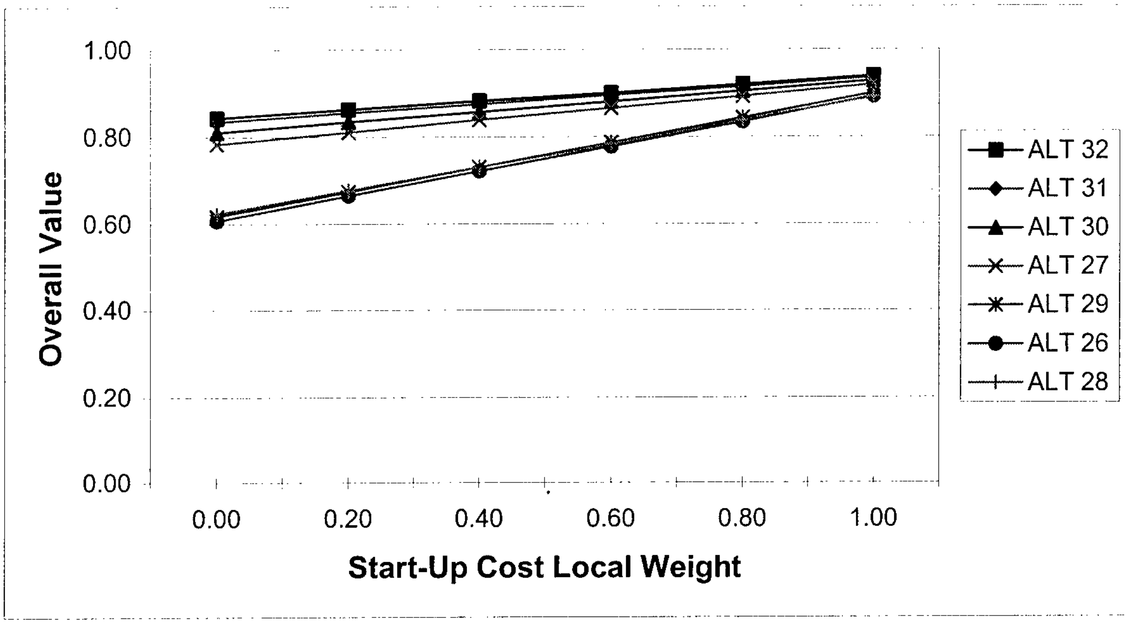


Figure 43. Sensitivity Analysis on Start-Up Cost Local Weight

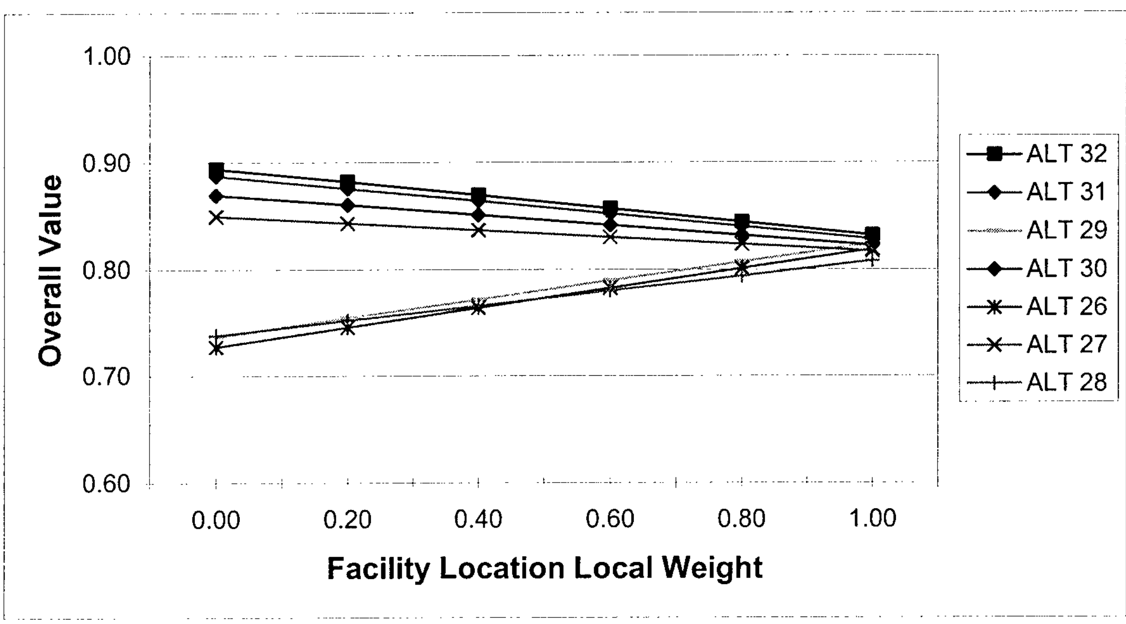


Figure 44. Sensitivity Analysis on Facility Location Local Weight

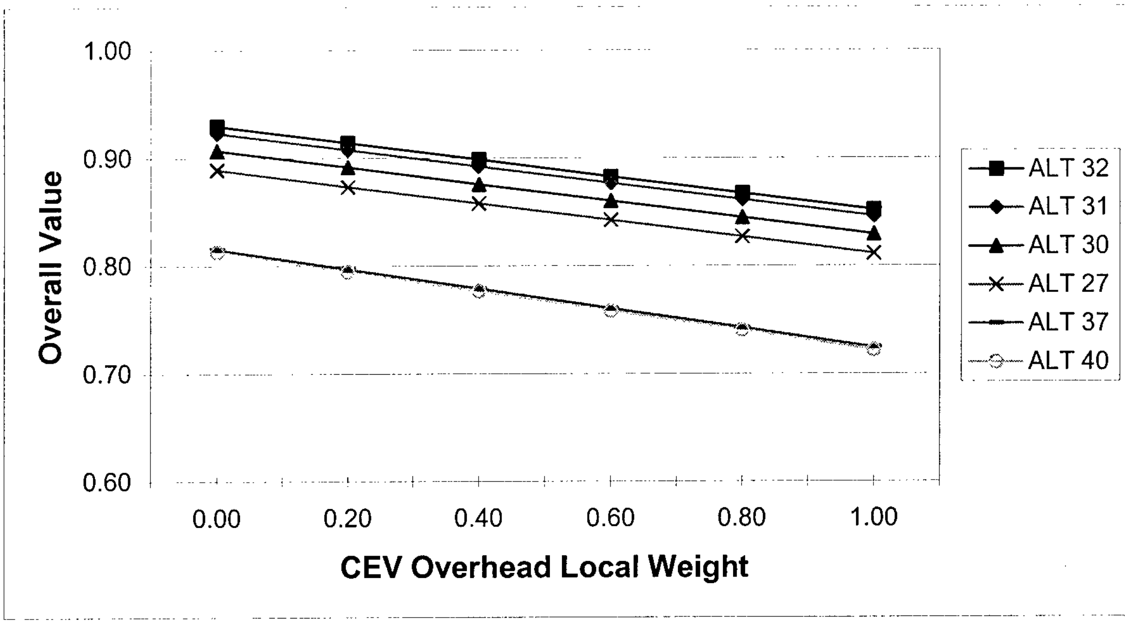


Figure 45. Sensitivity Analysis on CEV Overhead Local Weight

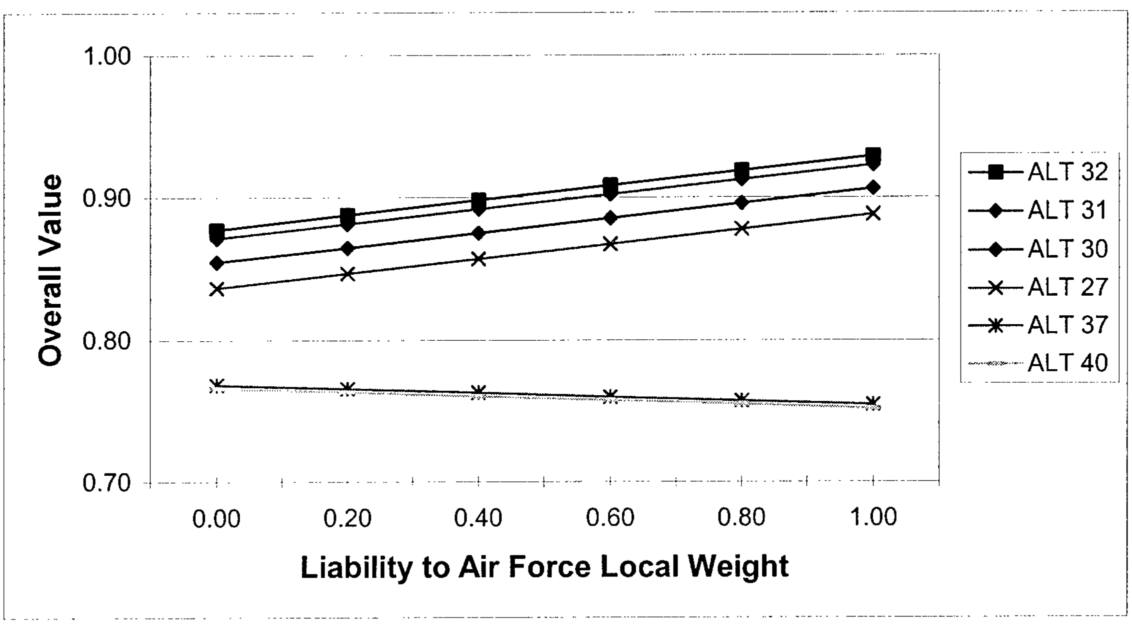


Figure 46. Sensitivity Analysis on Liability to Air Force Local Weight

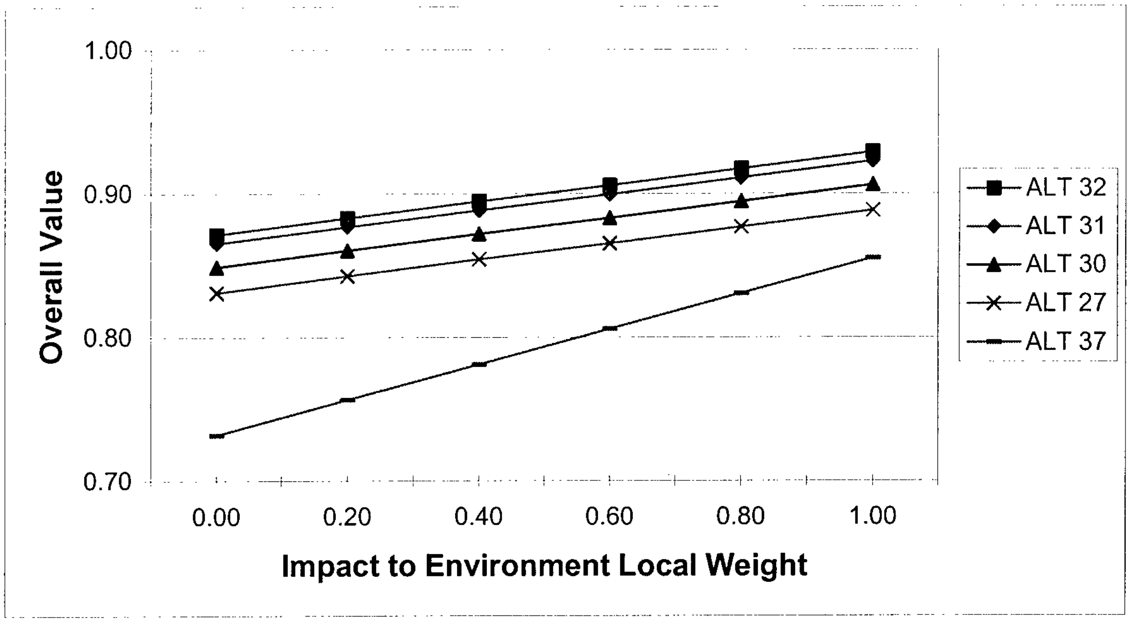


Figure 47. Sensitivity Analysis on Impact to Environment Local Weight

Appendix M: Model Formulas

The Excel spreadsheet cell formulas used in this model are several dozens of pages long due to the number of alternatives evaluated by the model and model formulation. For this reason, a printout of the cell formulas for the entire model will not be provided in this document. The previous appendices do provide all the calculation results used in the model as well as footnotes as to how some of the calculations were made. If the reader is interested in obtaining a copy of the Excel file used in this thesis or a copy of the Excel cell formulas used in the model, they can be obtained free from the author at mshoviak@hotmail.com.

The purpose of this appendix is to provide the reader with a general understanding of the cell formulas for the calculations in the model that are not obvious or apparent.

Appendix K: Single-Dimensional Value Function Equations

Facility Size (Cell C5)
=IF($B$5<=52000,1,IF($B$5<=62400,(1-(0.05/10400)*($B$5-
52000)),IF($B$5<=70200,(0.95-(0.2/7800)*($B$5-62400)),IF($B$5<=78000,(0.75-
(0.25/7800)*($B$5-70200)),IF($B$5<=85800,(0.5-(0.25/7800)*($B$5-
78000)),IF($B$5<=93600,(0.25-(0.2/7800)*($B$5-85800)),IF($B$5<=104000,(0.05-
(0.05/10400)*($B$5-93600)),0)))))))

Start-Up Cost (Cell C6)
=IF($B$6<=1000000,1,IF($B$6<=2000000,(1-(0.25/1000000)*($B$6-
1000000)),IF($B$6<=3000000,(0.75-(0.25/1000000)*($B$6-
2000000)),IF($B$6<=4000000,(0.5-(0.25/1000000)*($B$6-
3000000)),IF($B$6<=5000000,(0.25-(0.25/1000000)*($B$6-4000000)),0)))))

Recurring O&M Cost (Cell C7)
=IF($B$7<=10000,1,IF($B$7<=50000,(1-(1/40000)*($B$7-10000)),0))

Facility Location (Cell C8)
=IF($B$8<=0,1,IF($B$8<=0.5,(1-(0.25/0.5)*($B$8-0)),IF($B$8<=1,(0.75-(0.65/0.5)*($B$8-0.5)),IF($B$8<=3,(0.1-(0.1/2)*($B$8-1)),0))))

Waste Diversion (Cell C9)
=IF($B$9<=0,0,IF($B$9<=10,((0.5/10)*$B$9),IF($B$9<=20,(0.5+(0.3/10)*($B$9-10)),IF($B$9<=30,(0.8+(0.1/10)*($B$9-20)),IF($B$9<=40,(0.9+(0.05/10)*($B$9-30)),IF($B$9<=50,(0.95+(0.05/10)*($B$9-40)),1))))))

Implementation Time (Cell C10)
=IF($B$10<=1,1,IF($B$10<=2,(1-(0.1/1)*($B$10-1)),IF($B$10<=3,(0.9-(0.3/1)*($B$10-2)),IF($B$10<=4,(0.6-(0.3/1)*($B$10-3)),IF($B$10<=5,(0.3-(0.2/1)*($B$10-4)),IF($B$10<=6,(0.1-(0.1/1)*($B$10-5)),0))))))

CEV Overhead (Cell C11)
=IF($B$11<=40,1,IF($B$11<=160,(1-(1/120)*($B$11-40)),0))

Liability to AF (Cell C12)
=IF($B$12<=2,1,IF($B$12<=5,(1-(1/3)*($B$12-2)),0))

Impact to Environment (Cell C13)
=IF($B$13=1,1,IF($B$13=2,0.95,IF($B$13=3,0.9,IF($B$13=4,0.5,IF($B$13=5,0.45,IF($B$13=6,0.4,IF($B$13=7,0.1,IF($B$13=8,0,0))))))))

Appendix K: Overall Value Function Equation (Cell AF37)

=M37*$E$5+O37*$E$6+Q37*$E$7+S37*$E$8+U37*$E$9+W37*$E$10+Y37*$E$11+AB37*$E$12+AD37*$E$13

Formula for Cell Appendix K AF37 (in Words)

= (Facility Size Score*Facility Size Global Weight) + (Start-Up Cost Score*Start-Up Cost Global Weight) + (Recurring O&M Score*Recurring O&M Global Weight) + (Facility Location Score*Facility Location Global Weight) + (Waste Diversion Score*Waste Diversion Global Weight) + (Implementation Time Score*Implementation Time Global Weight) + (CEV Overhead Score*CEV Overhead Global Weight) + (Liability to AF Score*Liability to AF Global Weight) + (Impact to Environment Score*Impact to Environment Global Weight)

Key:
Bolded words represent column headings in the model.
Italicized words represent parameters used in the model. In the spreadsheet, these parameter names are actually number values.

Compacted Volume to Landfill

Excel Formula for Appendix E Cell B84
=IF('Appendix C'!D47=1, (($B$7*($F$17+$F$18+$F$19+$F$20+$F$21+$F$22+$F$27+$F$28+$F$29+$F$34+$F$36+$F$37+$F$38)+($E$24+$E$25+$E$26+$E$31+$E$32+$E$33+$E$39))+((1-$B$7)*($E$17+$E$18+$E$19+$E$20+$E$21+$E$22+$E$27+$E$28+$E$29+$E$34+$E$36+$E$37+$E$38))),SUM($E$17:$E$39))+IF('Appendix C'!F47=1,-($B$7*($E$25+$E$26)),0)+IF('Appendix C'!G47=1,-($B$7*$E$24),0)+IF(('Appendix C'!K47+'Appendix C'!D47)=2,-($B$7*$F$22),0)+IF(('Appendix C'!K47+'Appendix C'!E47)=2,-($B$7*($E$17+$E$19+$E$21+$E$22)),0)+IF(('Appendix C'!E47+'Appendix C'!H47+'Appendix C'!L47)=3,-($B$7*($E$17+$E$19+$E$21))+IF(('Appendix C'!I47+'Appendix C'!E47)=2,-($B$7*$E$18),0))

Formula for Cell Appendix E B84 (in Words)
{IF **Incinerating**, THEN [(*Recovery Rate* * **Volume After Incineration** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather)*) + (**Compacted Volume in Landfill** (*Glass + Aluminum + Bi-metal/Tin + Ferrous + Nonferrous + Other Metals*) + (1 – Recovery Rate)* (**Compacted Volume in Landfill** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather)*], ELSE (SUM(**Compacted Volume in Landfill**(*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather + Glass + Aluminum + Bi-metal/Tin + Ferrous + Nonferrous + Other Metals)*}
+ {IF **Recycling Aluminum/Steel Cans**, THEN –(*Recovery Rate** **Compacted Volume in Landfill**(*Aluminum/Steel Cans*)), ELSE 0}
+ {IF **Recycling Glass**, THEN –(*Recovery Rate** **Compacted Volume in Landfill**(*Glass*)), ELSE 0}
+ {IF **Incinerating and Composting**, THEN –(*Recovery Rate** **Volume After Incineration** (*Food Waste*)), ELSE 0}
+ {IF **Not Incinerating and Composting**, THEN –(*Recovery Rate** **Compacted Volume in Landfill** (*High Grade Office + Newspaper + Mixed Paper + Food Waste*)), ELSE 0}
+ {IF **Not Incinerating and Not Composting and Recycling Paper**, THEN –(*Recovery Rate** **Compacted Volume in Landfill** (*High Grade Office + Newspaper + Mixed Paper*)), ELSE 0}
+ {IF **Not Incinerating and Recycling Cardboard**, THEN –(*Recovery Rate** **Compacted Volume in Landfill** (*Corrugated*)), ELSE 0}

Volume to Incinerate

<u>Excel Formula for Appendix E Cell C84</u>
=IF('Appendix C'!D47=1, ($B$7*($C$17+$C$18+$C$19+$C$20+$C$21+$C$22+$C$27+$C$28+$C$29+$C$34+$C$36+$C$37+$C$38)),0)-IF(('Appendix C'!D47+'Appendix C'!K47)=2,($B$7*$C$22),0)

<u>Formula for Cell Appendix E C84 (in Words)</u>
{IF **Incinerating**, THEN [(*Recovery Rate* * **Uncompacted Annual Estimated Volume** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather))*], ELSE 0}
- {IF **Incinerating and Composting**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume** (*Food Waste*)), ELSE 0}

Volume to Recycle

<u>Excel Formula for Appendix E Cell D84</u>
=IF('Appendix C'!F47=1,($B$7*($C$25+$C$26)),0)+IF('Appendix C'!G47=1,$B$7*$C$24,0)+IF('Appendix C'!H47=1,($B$7*($C$17+$C$19+$C$21)),0)+IF('Appendix C'!I47=1,$B$7*$C$18,0)

<u>Formula for Cell Appendix E D84 (in Words)</u>
{IF **Recycling Aluminum/Steel Cans**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume** (*Aluminum/Steel Cans*)), ELSE 0}
+ {IF **Recycling Glass**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume** (*Glass*)), ELSE 0}
+ {IF **Recycling Paper**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume**(*Paper*)), ELSE 0}
+ {IF **Recycling Cardboard**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume**(*Corrugated*)), ELSE 0}

Volume to Compost

<u>Excel Formula for Appendix E Cell D84</u>
=IF(('Appendix C'!K47+'Appendix C'!E47)=2,($B$7*($C$17+$C$19+$C$21+$C$22)),0)+IF(('Appendix C'!K47+'Appendix C'!D47)=2,($B$7*$C$22),0)

<u>Formula for Cell Appendix E D84 (in Words)</u>
{IF **Not Incinerating and Composting**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume** (*High Grade Office + Newspaper + Mixed Paper + Food Waste*)), ELSE 0}
+ {IF **Incinerating and Composting**, THEN (*Recovery Rate** **Uncompacted Annual Estimated Volume** (*Food Waste*)), ELSE 0}

Estimated Landfill Cost

Excel Formula for Appendix F Cell K40
=SUM($F$32+$F$34+$F$35+$F$36)

Formula for Cell Appendix E K40 (in Words)
Class III Landfill Total Cost

Estimated Incineration Cost

Excel Formula for Appendix F Cell L40
=IF('Appendix C'!D47=1,$F$80,0)

Formula for Cell Appendix E L40 (in Words)
IF **Incinerating**, THEN (Incinerator Total Cost), ELSE 0

Estimated Recycling Cost

Excel Formula for Appendix F Cell M40
=IF('Appendix C'!J47=1,0,SUM($F$88:$F$90))+IF(('Appendix C'!F47+'Appendix C'!I47)>0,SUM($F$84:$F$85),0)+IF('Appendix C'!G47=1,SUM($F$86:$F$87),0)

Formula for Cell Appendix E M40 (in Words)
IF **No Recycling Aluminum/Steel Cans**, THEN 0, ELSE (Recycling Bin Costs)
+ IF **Recycling Aluminum/Steel Cans** or **Recycling CardboardGlass**, THEN (Equipment and Installation Cost for a Baler), ELSE 0
+ IF Recycling Glass, THEN (Equipment and Installation Cost for Pulverizer), ELSE 0

Estimated Composting Cost

Excel Formula for Appendix F Cell N40
=IF('Appendix C'!K47=1,$F$100,0)

Formula for Cell Appendix E N40 (in Words)
IF **Composting**, THEN (Composting Total Cost), ELSE 0

Landfill (lbs)

Excel Formula for Appendix G Cell B77
=IF('Appendix C'!D47=1,(($B$2*($C$12+$C$13+$C$14+$C$15+$C$16+$C$17+$C$22+$C$23+$C$24+$C$29+$C$31+$C$32+$C$33)+($B$19+$B$20+$B$21+$B$26+$B$27+$B$28+$B$34))+((1-$B$2)*($B$12+$B$13+$B$14+$B$15+$B$16+$B$17+$B$22+$B$23+$B$24+$B$29+$B$31+$B$32+$B$33))),SUM($B$12:$B$34))+IF('Appendix C'!F47=1,-($B$2*($B$20+$B$21)),0)+IF('Appendix C'!G47=1,-($B$2*$B$19),0)+IF(('Appendix C'!K47+'Appendix C'!D47)=2,-($B$2*$C$17),0)+IF(('Appendix C'!K47+'Appendix C'!E47)=2,-($B$2*($B$12+$B$14+$B$16+$B$17)),0)+IF(('Appendix C'!E47+'Appendix C'!H47+'Appendix C'!L47)=3,-($B$2*($B$12+$B$14+$B$16))+IF(('Appendix C'!I47+'Appendix C'!E47)=2,-($B$2*$B$13),0))

Formula for Cell Appendix G B77 (in Words)
{IF **Incinerating**, THEN [(*Recovery Rate* * **Weight After Incineration** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather))* + (**Annual Estimated Weight** (*Glass + Aluminum + Bi-metal/Tin + Ferrous + Nonferrous + Other Metals*) + (1 – Recovery Rate)* **(Annual Estimated Weight** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather)*], ELSE (SUM(**Annual Estimated Weight** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather + Glass + Aluminum + Bi-metal/Tin + Ferrous + Nonferrous + Other Metals)*}
+ {IF **Recycling Aluminum/Steel Cans**, THEN –(*Recovery Rate** **Annual Estimated Weight** (*Aluminum/Steel Cans*)), ELSE 0}
+ {IF **Recycling Glass**, THEN –(*Recovery Rate** **Annual Estimated Weight** (*Glass*)), ELSE 0}
+ {IF **Incinerating and Composting**, THEN –(*Recovery Rate** **Weight After Incineration** (*Food Waste*)), ELSE 0}
+ {IF **Not Incinerating and Composting**, THEN –(*Recovery Rate** **Annual Estimated Weight** (*High Grade Office + Newspaper + Mixed Paper + Food Waste*)), ELSE 0}
+ {IF **Not Incinerating and Not Composting and Recycling Paper**, THEN –(*Recovery Rate** **Annual Estimated Weight** (*High Grade Office + Newspaper + Mixed Paper*)), ELSE 0}
+ {IF **Not Incinerating and Recycling Cardboard**, THEN –(*Recovery Rate** **Annual Estimated Weight** (*Corrugated*)), ELSE 0}

Incinerate (lbs)

Excel Formula for Appendix G Cell C77
=IF('Appendix C'!D47=1,($B$2*($B$12+$B$13+$B$14+$B$15+$B$16+$B$17+$B$22+$B$23+$B$24+$B$29+$B$31+$B$32+$B$33)),0)-IF(('Appendix C'!D47+'Appendix C'!K47)=2,($B$2*$B$17),0)

Formula for Cell Appendix G C77 (in Words)
{IF **Incinerating**, THEN [(*Recovery Rate* * **Annual Estimated Weight** (*High Grade Office + Corrugated + Newsprint + Magazines + Mixed Paper + Food Waste + Plastic PETE (1) + Plastic HDPE (2) + Other Plastics + Wood + Textiles + Rubber + Leather))*], ELSE 0}
- {IF **Incinerating and Composting**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Food Waste*)), ELSE 0}

Al Cans to Recycle (lbs)

Excel Formula for Appendix G Cell D77
=IF('Appendix C'!$F47=1,($B$2*B$20),0)

Formula for Cell Appendix G D77 (in Words)
{IF **Recycling Aluminum**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Aluminum Cans*)), ELSE 0}

Steel Cans to Recycle (lbs)

Excel Formula for Appendix G Cell E77
=IF('Appendix C'!$F47=1,($B$2*$B$21),0)

Formula for Cell Appendix G E77 (in Words)
{IF **Recycling Steel Cans**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Steel Cans*)), ELSE 0}

Glass to Recycle (lbs)

Excel Formula for Appendix G Cell F77
=IF('Appendix C'!$G47=1,$B$2*$B$19,0)

Formula for Cell Appendix G F77 (in Words)
{IF **Recycling Glass**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Glass*)), ELSE 0}

Paper to Recycle (lbs)

<u>Excel Formula for Appendix G Cell G77</u>
=IF('Appendix C'!$H47=1,($B$2*($B$12+$B$14+$B$16)),0)
<u>Formula for Cell Appendix G G77 (in Words)</u>
{IF **Recycling Paper**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Paper*)), ELSE 0}

Cardboard to Recycle (lbs)

<u>Excel Formula for Appendix G Cell H77</u>
=IF('Appendix C'!$I47=1,$B$2*$B$13,0)

<u>Formula for Cell Appendix G H77 (in Words)</u>
{IF **Recycling Cardboard**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Corrugated*)), ELSE 0}

Compost (lbs)

<u>Excel Formula for Appendix G Cell I77</u>
=IF(('Appendix C'!K47+'Appendix C'!E47)=2,($B$2*($B$12+$B$14+$B$16+$B$17)),0)+IF(('Appendix C'!K47+'Appendix C'!D47)=2,($B$2*$B$17),0)

<u>Formula for Cell Appendix G I77 (in Words)</u>
{IF **Not Incinerating and Composting**, THEN (*Recovery Rate** **Annual Estimated Weight** (*High Grade Office + Newspaper + Mixed Paper + Food Waste*)), ELSE 0} + {IF **Incinerating and Composting**, THEN (*Recovery Rate** **Annual Estimated Weight** (*Food Waste*)), ELSE 0}

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Vita

Captain Mark J. Shoviak was born on [redacted] in Toledo, Ohio. He graduated from Central Catholic High School in 1989 and entered undergraduate studies at the University of Toledo. He earned a Bachelor of Science degree in Electrical Engineering from the University and was commissioned through the Reserve Officer Training Corps, Detachment 620, Bowling Green State University, in June 1993.

His first assignment was to March AFB, California. While there, he served as a project engineer in the maintenance engineering section and later as squadron section commander of the 722d Civil Engineer Squadron. His next assignment was to Elmendorf AFB, Alaska, where he served as Chief of Construction and as a project engineer in the environmental compliance section of the 611th Civil Engineer Squadron. In August 1999, he entered the Engineering and Environmental Management Program, Graduate School of Engineering and Management, Air Force Institute of Technology. Following graduation, Captain Shoviak will join the Headquarters Air Force Space Command Civil Engineer's staff.

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14. ABSTRACT

Eareckson Air Station (AS), a remote U.S. Air Force installation, faces the complex decision of selecting a new municipal solid waste (MSW) management strategy to replace its current non-compliant system. This research effort applies value-focused thinking and multiattribute preference theory to decision analysis techniques to produce a multiple-objective decision analysis model that captures all of the site's MSW goals, objectives, and concerns in order to facilitate the evaluation of MSW management strategies available. The model ranks 40 specific MSW management alternatives, which were developed in accordance with the decision-maker's assumptions and constraints, based on how well they meet Eareckson's overall strategic objective, a 20-year compliant MSW system. The model provides insight to the decision-maker as to which strategy is best suited for Eareckson's MSW management needs. Sensitivity analysis is incorporated in the model to assess and illustrate the effects of changes in model objective weights and changes in model parameters. Overall, the model provides the Eareckson AS decision-maker with a decision tool to make a better decision when choosing a new MSW management strategy.

15. SUBJECT TERMS

Waste Management, Integrated Solid Waste Management, Municipal Solid Waste Management, Value-Focused Thinking, Multiattribute Preference Theory

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